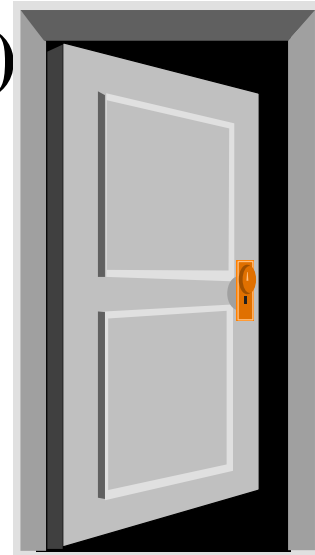


# **STATISTICAL GUIDE**

## **FOR DCMC PERSONNEL**

**Statistical Process Control (SPC)  
and  
Other Statistical Tools**



## **“STATISTICAL PROBLEM GUIDE”**

### **PURPOSE**

---

This guide will:

Assist in-plant and staff personnel in using Contractor data/(information) systems to answer questions about contractor performance.

Help DCMC personnel organize, analyze and use Data (information) to answer performance questions.

Assist staff personnel in using in-house data systems to answer management and performance questions.

Help explain/review statistical tools that can be used to answer in-plant and staff questions.

Review SPC control Charts and how to use them.

Provide DCMC personnel with some decision making Guidance and provide rationale for selecting the proper tool to answer in-plant and management questions.

Explain how to use some of the tools in “EXCEL and Powerpoint for Windows” Statistical and graphic software packages, and let the computer execute/work for you.

## **FOREWARD**

---

Introduction: The Defense Contract Management Command (DCMC) has developed a DCMC home page on the Internet. Also, available through the internet is the DLA home page. Both home pages provide a plethora of data to all DLA/DCMC personnel through various information systems. These information systems can assist in accessing performance measures and in establishing priorities for daily agency business. The data retrieval system called "Power Play" has been extremely helpful in obtaining data as well as providing the capability to slice and dice this data into meaningful metrics. The recent establishment of the Shared Data Warehouse, (SDW) data bases and the ability to use "Power Play" has greatly enhanced DCMC/DLA data analyses.

These systems:

- focus externally on the DLA/DCMC customer.
- can measure effectiveness and efficiency against past performance and related performance standards.
- can greatly assist in preparing Monthly Management Review (MMR) data.
- can assist in-plant and staff personnel on where to concentrate their efforts.

Executive level managers will use this system to see where their organizations are, where they have been and where they are going.

## **FORWARD, CONTINUED**

Background: For many of us statistics are at best difficult with formidable obstacles. The ability to develop, analyze and use data has been and continues to be a problem both in-plant and at the managerial level.

Goal/Aim: The purpose of this guide is to provide Practical problems/examples for both in-plant and management DCMC personnel and use basic statistical tools to effectively solve these problems. The overall goal is to get you to think statistically rather than anecdotally whether working in management, on staff or in-plant. The guide provides DCMC personnel with a reference of systematically solved statistical problems including all the different types of Statistical Process Control (SPC) charts as well as other problems in real world settings.

Requirements: In order to better learn from this guide, you will need to be able to access and use Powerpoint and EXCEL software for windows. You will need at least 2-3 hour block of uninterrupted time to input and get products from Powerpoint software as you follow through the guide.

### **Questions to ask and answer!**

1. ***How can we Paint a Picture of the Information?***
2. ***How can we describe the Norm in the information?***
3. ***What does the spread of the data look like?***
4. ***How do we determine which statistical tool to use?***
5. ***How do we ascertain process capability and performance?***
6. ***How can we make management predictions?***
7. ***How can we make management decisions?***
8. ***Do relationships exist between different groups of data?***
9. ***How can we determine the strength of relationship?***
10. ***Can we model relationships to make Management predictions/decisions?***

## Overview

---

The following is a systematic approach to use when solving problems that require the use of mathematics and/or statistics:

- \* Read the information that is available.
- \* Try to get an insight into what is happening. You may even wish to form your own hypothesis from the information.
- \* What is in the picture? Do we have data? Is the data available? Is the data variable or attribute?
- \* Is the data in a form we can use to analyze it? How do we show the spread of the data?
- \* Can we use an EXCEL spread sheet to record and manipulate the data?
- \* Can we create graphs? What kind: Run charts, Histograms?
- \* How do we display graphs: histograms, run charts, control charts, and others.
- \* Can we do a Customer Satisfaction Score Chart? What does it tell us?
- \* What picture is the most appropriate to use?
- \* Can we summarize our work?

## **“STATISTICAL PROBLEM GUIDE”**

### ***INDEX OF TYPES OF PROBLEMS BY PAGE:***

Purpose.....	page...1
Forward.....	page...2
Overview.....	page...4
Index of types of problems by page.....	page...5
Problem 1 Trend charts.....	page...6
Problem 2 Pareto charts, Defects per Unit/Defects per opportunity.....	page..12
Problem 3 Process Capability, Standard Normal ‘Z’ values and AQLs.....	page..20
Problem 4 Histograms, Variables data, Xbar and R Statistical Process Control (SPC) Charts, Process Capability and Performance.....	page..24
Problem 5 SPC ‘p’ chart Attribute data, Fractional defectives.....	page..32
Problem 6 SPC ‘c’ chart Attribute data, Number of defects.....	page..38
Problem 7 SPC ‘u’ chart Attribute data, defects per unit.....	page..44
Problem 8 SPC ‘np’ chart Attribute data, Number defective.....	page..54
Problem 9 SPC Individual ‘X’ and Moving range Chart, Central Limit Theorem, Single readings.....	page..59
Problem10 Short Run SPC ‘Target Chart’, Variables Data, multiple parts...	page..69
Epilogue.....	page..80

**Example #1**

This is an example for a district staff or in-plant  
DCMC personnel.

Lately there have quite a number of transformers made by ABC corporation that need rework or have to be scraped. This additional time may cause the contract to be delinquent. The Government Plant Representative talks with the contractor's Quality control who states that a number of new inspectors have been hired and they are really strict. Another Contractor's QC person thinks that the company has been dealing with a couple of new vendors.

You must alert the customer to what is happening. What do you do? Give a anecdotal response based on what the contractor's people have told you, or do some you own research to find out the actual/real cause of the problem(s) facing this company. We won't really know until we begin to think statistically. You must ask yourself the question, if the new inspectors are finding problems now, why haven't you found these problems before when looking at these transformers when performing product audits. You need to see what data is available to more closely analyze the problem situation.

The contractor's data on a transformer shows the following First Pass Yield Data:

#	UNITS	# DEFECTS	TYPES OF DEFECTS				DATE
			01	02	03	04	
40		6	4	0	1	1	7/15/96
40		4	1	2	0	1	8/10/96
30		1	0	1	0	0	8/31/96
30		5	1	2	1	1	9/05/96
40		6	2	1	1	2	9/15/96
30		4	1	2	1	0	9/20/96
30		5	2	2	0	1	9/30/96
30		5	1	3	1	0	10/05/96
30		6	2	3	1	0	10/08/96
30		8	3	2	1	2	10/22/96
30		8	4	2	1	1	10/28/96
40		10	6	3	0	1	11/10/96
40		8	5	2	1	0	11/15/96
30		12	8	2	1	1	11/30/96
40		12	7	3	0	2	12/06/96
30		11	7	2	1	1	12/15/96
40		14	10	1	2	1	12/21/96
30		13	9	2	1	1	1/05/97
30		12	9	3	0	0	1/11/97
30		13	9	1	2	1	1/15/97
Totals		163	91	39	16	17	

**DEFECT CODES**

01 = HIGH POT FAILURE  
02 = LOW OUTPUT VOLTAGE  
03 = WORKMANSHIP DEFECTS  
04 = UNBALANCED OUTPUT VOLTAGE

#### QUESTIONS:

##### What should be done?

1. Determine the First Pass Yields?
2. What does this data show you?
3. What else do you want to do with this data?
4. How do you interpret the chart(s) that you made?
5. Should a CIO be issued? Why? or Why not?

# EXAMPLE #1

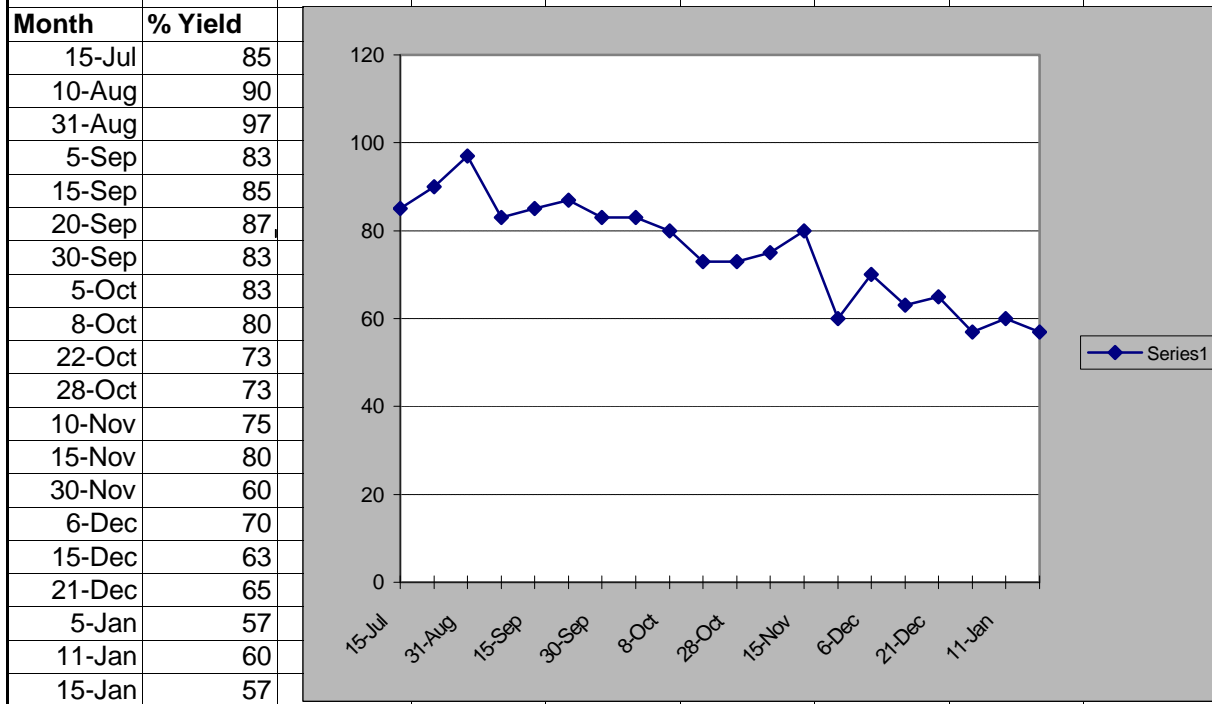
## Calculations

- FIRST PASS YIELD =  $\frac{\text{Total number of good unit}}{\text{Total number of units}}$ 
  - Tot units = 40   Defectives = 6   Good = 34
  - FPY =  $34/40 = .8500 = .85$  or 85%
- This data should be placed on a Trend/Run chart and analyzed.
- Use “EXCEL” to enter the data and Powerpoint to draw the line graph. Note how easy it is to import the data sheet from EXCEL to Powerpoint.
- Note that due to the small number of defect codes, it is not necessary to place these data on a Pareto chart. We should be able to see that the major problem is high pot failures.
- If in-plant, a CIO may be issued. We should first speak to the contractor to see whether or not he is aware of the new high number of high pot problem and the new vendor supplying them.

# EXAMPLE #1

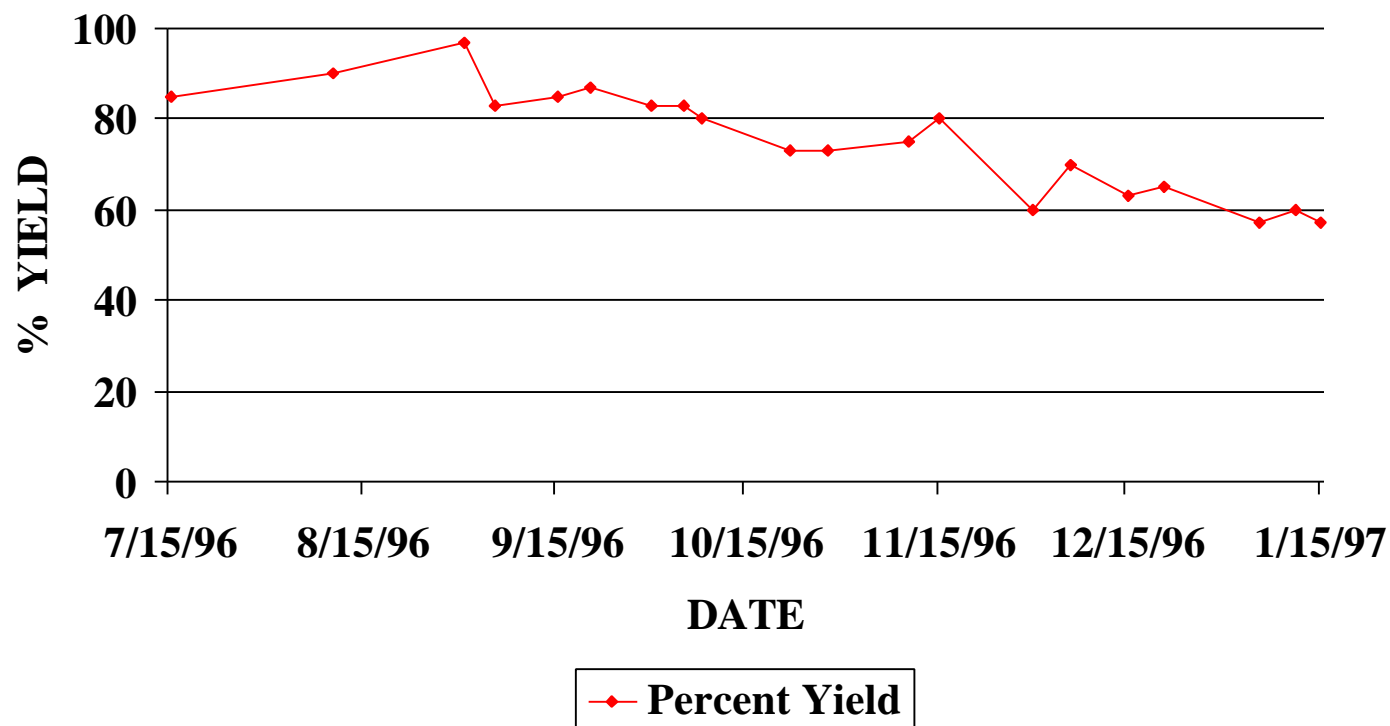
First Pass Yield: Transformer nonconformances

## FIRST PASS YIELD



# EXAMPLE #1

## First Pass Yield: Transformer Nonconformances



## SUMMARY

Whether using EXCEL or Powerpoint's graphic capabilities, (both provided), the First Pass Yield exhibits a continuous downward trend and a significantly large number of high pot failures. The high pot failures started to become a serious problem starting in November when the contractor hired a new vendor to supply the high pot components. Over the next 2 months high pot failures have greatly increased. Before November the highest high pot failures found in any lot was 4. After November the smallest number of high pot failures was greater than 4 having an average of 7.77 failures for every 30 tested. Contractor Quality control finds the defects and has them fixed, however, no analyses are performed on the statistical data available. The rework is time consuming and getting totally out of control thus, threatening the transformer delivery schedule.

A Continuous Improvement Opportunity (CIO) should be issued to the contractor explaining all of the findings. A corrective action should also be issued outlining the problem this contractor is having with vendor supplied parts/components.

## Example #2

This is an example useful to DCMC in-plant QA personnel, and District/CAO staff and engineers.

The customer wishes to know what is the biggest problem with these boards? They are receiving them late and their reliability leaves much to be desired. A reliable member of the of the contractor Quality Control and testing Division tells you that the problem is that the new solders hired frequently have problems with excess solder, insufficient solder and cold solder joints. Note that an anecdotal response would be to just parrot the contractor's QC man's response to your customer. But we can and will do better. Looking at the specific PC board in question for critical defects the following defects were detected:

Defect Codes											
Date	Sample Size	6015	6016	6017	6018	6019	6020	6021	6022	6023	6024
01/03/97	50	3	0	2	1	0	0	0	3	0	0
01/04/97	50	0	0	2	0	0	0	0	0	0	4
01/05/97	50	0	0	3	0	0	0	1	2	0	3
01/08/97	50	2	0	2	0	0	1	0	2	0	0
01/09/97	50	1	0	4	0	0	0	0	0	0	1
01/10/97	50	0	0	1	0	0	0	0	1	0	0
01/13/97	50	0	0	3	0	0	1	0	1	0	0
01/14/97	50	0	0	2	0	0	0	0	0	1	1
01/15/97	50	0	0	0	0	0	0	2	0	0	2
01/17/97	50	3	0	4	0	0	0	0	1	0	0
01/18/97	50	4	0	2	0	0	1	0	0	0	0
01/19/97	50	0	0	3	0	1	0	0	0	0	1
Totals	600/72	13	0	28	1	1	3	3	10	1	12

<u>CODES</u>	<u>DESCRIPTION</u>	<u>COST OF DEFECT</u>
6015	Cold solder joint	\$ 40.00
6016	Workmanship	\$ 7.50
6017	Excess solder	\$ 25.00
6018	Flux excess	\$ 10.00
6019	Burned joint	\$ 95.00
6020	Disconnected or broken lead	\$ 20.00
6021	Broken IC component	\$ 400.00
6022	Lifted circuit pad	\$ 80.00
6023	Cracked PC board	\$ 400.00
6024	Insufficient solder	\$ 15.00

## QUESTIONS?

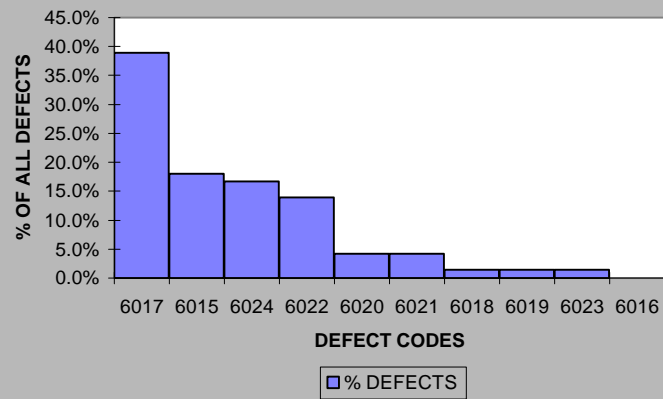
### What should be done?

1. Analyze the data above.
2. What is Stratification? Can data mask the real problems?
3. What are your 3 worst problems?  
(Hint) a. Stratify by number of defects  
b. Stratify by total cost
4. Are the problems the same when stratified differently?
5. Find Defects Per Unit (DPU) and Defects Per Opportunity (DPO), given that each PC board has 100 opportunities for defects.
6. What action, if any, should be taken?

## EXAMPLE #2

### PARETO CHART (DEFECTS)

CODES	% DEFECTS
6017	38.9%
6015	18.1%
6024	16.7%
6022	13.9%
6020	4.2%
6021	4.2%
6018	1.4%
6019	1.4%
6023	1.4%
6016	0.0%

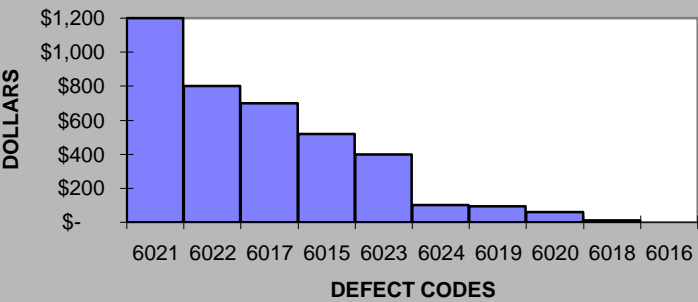


**EXAMPLE #2**

**PARETO CHART (DOLLARS)**

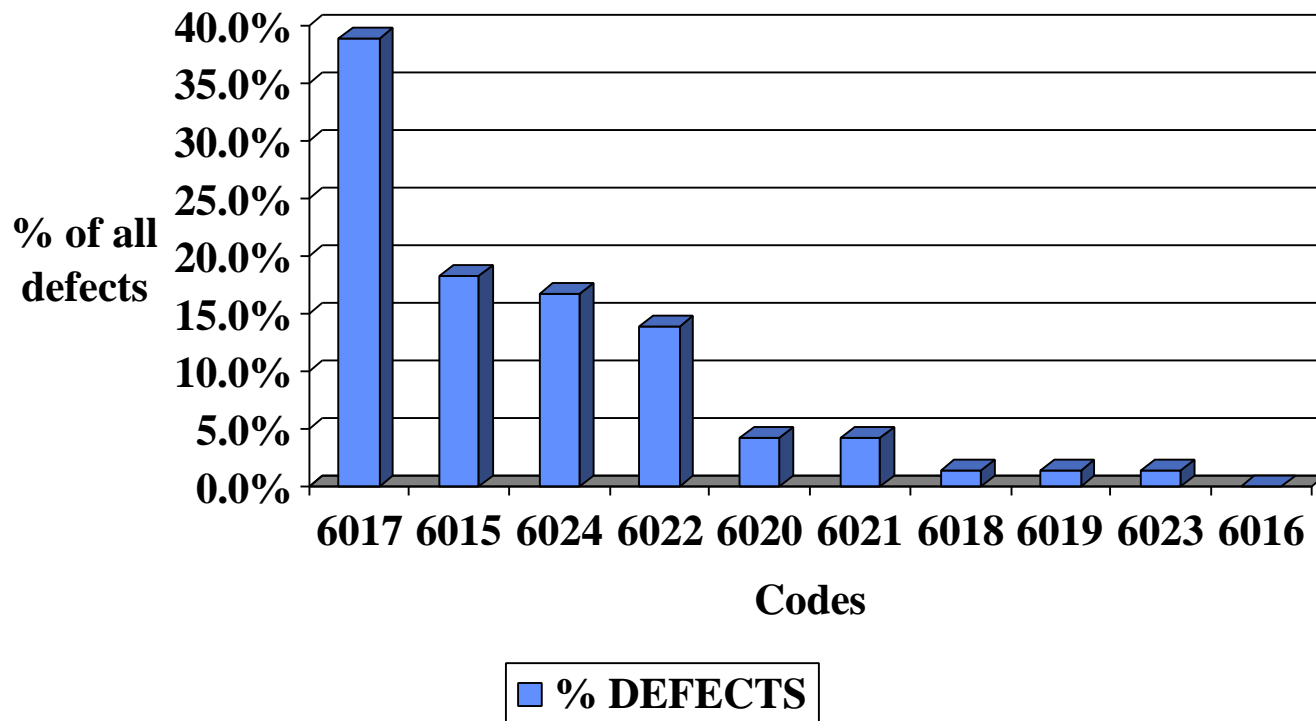
**CODES**   **COST IN \$\$**

6021	\$ 1,200
6022	\$ 800
6017	\$ 700
6015	\$ 520
6023	\$ 400
6024	\$ 100
6019	\$ 95
6020	\$ 60
6018	\$ 10
6016	\$ -



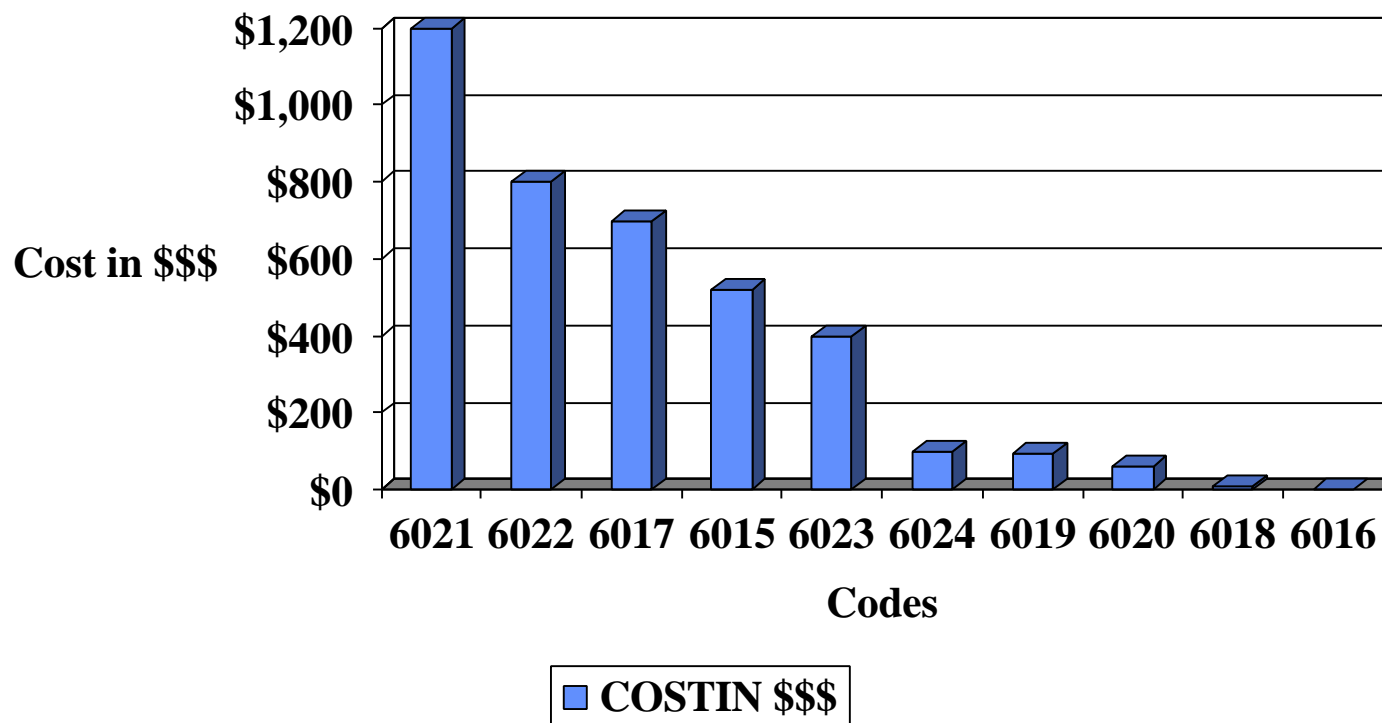
# EXAMPLE #2

## PARETO CHART (DEFECTS)



# EXAMPLE #2

## PARETO CHART (DEFECTS)



# EXAMPLE #2

**DEFECTS PER UNIT (DPU); PER OPPORTUNITY (DPO)**

SAMPLE NUMBER	SAMPLE SIZE	NO. OF DEFECTS	OPPRTUN FOR DEF	DPU VALUE	DPO VALUE
1	50	9	5000	.18	.0018
2	50	6	5000	.12	.0012
3	50	9	5000	.18	.0018
4	50	7	5000	.14	.0014
5	50	6	5000	.12	.0012
6	50	2	5000	.04	.0004
7	50	5	5000	.10	.0010
8	50	4	5000	.08	.0008
9	50	4	5000	.08	.0008
10	50	8	5000	.16	.0016
11	50	7	5000	.14	.0014
12	50	5	5000	.10	.0010
TOTAL	600	72	60000	.12	.0012

## SUMMARY

Note that the guide provides Pareto charts made by both EXCEL and Powerpoint. When the data is stratified according to the number of defects, the 3 worst problems are: Excess solder, cold solder joints and insufficient solder. When looking at cost as the most important factor, the 3 worst defects are: Broken IC component, lifted circuit pad and Excess solder. In conclusion, you need to know exactly what is more important to the customer? Money or Time. It seems that the buying command may be interested in both since they are dissatisfied with the delivery time as well as the reliability. Looking at the defects per unit the average is 12%. When looking at the defects per opportunity we see that that is just a little more than .1%. This is an intricate item and there are a lot of opportunities to make errors/mistakes. The contractor either needs very good and thorough inspectors or a piece of automated test equipment to do the job.

### **Example #3**

This is an example useful to DCMC QA in-plant personnel as well as District and CAO staff personnel

DCMC received a congressional complaint that an in-plant Quality Assurance Representative (QAR) was rejecting material in a plant of one of her constituents without just cause. It seems that a QAR in XYZ corporation has issued a Corrective Action Request (CAR) to this contractor for using O-rings from a process that has a Cpk (Performance index) of .66667. A check of the contractor's process has shown the Cpk value to be accurate. The contractor uses statistical control charts to monitor and control the process. A note on the drawing requires sampling in accordance with MIL-STD-105E General inspection level II, AQL 4.0%

The contractor was irate at receiving this CAR and contacted his congressman. The contractor claims that a Cpk = .66667 far surpasses the MIL-STD-105E requirement.

Assume a lot size of 1500, with specifications of  
6.650 +/- .125

**Questions to be answered by DCMC personnel; in-plant,  
District or CAO staff:**

1. Who is right?
2. Why are they right?
3. What can we do to ascertain who is correct?
4. What can we do to substantiate our findings?
5. What if the AQL was at 1.0%, would your findings still be the same?
6. Why or why not?

**Solution Hints:**

1. What does .66667 Cpk mean?
2. What is the percent defective for a Cpk of .66667?
3. What is the difference between Cp and Cpk?
4. What is the sample size for a lot of 1500?
5. What is the maximum percent defective for an AQL of 4.0%?
6. Is the process centered?
7. Who is right, the QAR or the contractor?
8. Do the same analysis for an AQL of 1.0%.

**Solution:**

Cp is the process capability index measuring the process spread with no regard to where it is centered. Cpk is the process performance index which compares the mean of the process to the nominal or mean tolerance dimension. Since 3 times the Cpk is equal to the "z" value of a standard normal distribution;  $3 \times .66667 = 2.000$  or shows a minimum of 95.44% good product or a maximum of 4.56% defective. Why a maximum? Because  $Cpk = \min(Cpu, Cpl)$ , so the Cpk is the smaller of the 2 values. Only if the process is exactly centered over the nominal or mean tolerance dimension will Cpu(Cp upper value) and Cpl(Cp lower value) be equal; exactly having 2.28% defective on both sides or 4.56% maximum defective.

MIL-STD-105E Table I says, that a lot size of 1500 level II requires a sample size code letter "K"; this is 125. With an AQL of 4.0%, the Accept/Reject criteria is Accept = 10 and Reject = 11. This means you may accept the entire lot of 1500 as long as you do not have more than 10 defectives in the lot of 125.  $10/125 = 8.00\%$ , this is almost twice as many defectives as the contractor's process is actually producing. The QAR should withdraw his corrective action request under these conditions.

When the AQL is 1.0%, the accept/reject criteria is Accept = 3, Reject = 4.  $3/125$  allows a total of 2.40% defective. As you can see from the above calculations the  $Cpk = .66667$  produces a minimum of 2.28% defective and a maximum of 4.56% defective. In this case the QAR could be justified in issuing a Corrective Action Request (CAR).

# **MIL-STD-105E TABLES**

Lot or Batch size			SPECIAL	INSPCT	LEVELS		GENERAL	INSP	LEVELS
			S-1	S-2	S-3	S-4	I	II	III
2	TO	8	A	A	A	A	A	A	B
9	TO	15	A	A	A	A	A	B	C
16	TO	25	A	B	B	B	B	C	D
26	TO	50	A	B	B	C	C	D	E
51	TO	90	B	B	C	C	C	E	F
91	TO	150	B	B	C	D	D	F	G
151	TO	280	B	C	D	E	E	G	H
281	TO	500	B	C	D	E	F	H	J
501	TO	1200	C	C	E	F	G	J	K
1201	TO	3200	C	D	E	G	H	K	L
3201	TO	10000	C	D	F	G	J	L	M
10001	TO	35000	C	D	F	H	K	M	N
35001	TO	150000	D	E	G	J	L	N	P
150001	TO	500000	D	E	G	J	M	P	Q
500001	TO	OVER	D	E	H	K	N	Q	R

SAMPLE SIZE		ACCEPTABLE QUALITY LEVELS (NORMAL INSPECTION)													
CODE LETTER	SAMPLE SIZE	0.65		1.0		1.5		2.5		4.0		6.5		--	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re		
A	2	0	1	0	1	0	1	0	1	0	1	0	1	xxx	
B	3	0	1	0	1	0	1	0	1	0	1	0	1	xxx	
C	5	0	1	0	1	0	1	0	1	0	1	0	1	xxx	
D	8	0	1	0	1	0	1	1	2	1	2	1	2	xxx	
E	13	0	1	0	1	0	1	1	2	1	2	2	3	xxx	
F	20	0	1	0	1	0	1	1	2	2	3	3	4	xxx	
G	32	1	2	0	1	1	2	2	3	3	4	5	6	xxx	
H	50	1	2	1	2	2	3	3	4	5	6	7	8	xxx	
J	80	1	2	2	3	3	4	5	6	7	8	10	11	xxx	
K	125	2	3	3	4	5	6	7	8	10	11	14	15	xxx	
L	200	3	4	5	6	7	8	10	11	14	15	21	22	xxx	
M	315	5	6	7	8	10	11	14	15	21	22	21	22	xxx	
N	500	7	8	10	11	14	15	21	22	21	22	21	22	xxx	
P	800	10	11	14	15	21	22	21	22	21	22	21	22	xxx	
Q	1250	14	15	21	22	21	22	21	22	21	22	21	22	xxx	
R	2000	21	22	21	22	21	22	21	22	21	22	21	22	xxx	

## SUMMARY

This example shows us that we must be very careful in interpreting Cp (Capability Index) and Cpk (Performance Index) values. We can not just go by the tables published in most books that say that if the Cpk is below 1.0, the process is not meeting Specifications, or that Cpk's between 1.0 and 1.33 are only nominally meeting specifications. Remember that the contractor and buying activity are both bound by the terms of the contract. These are the criteria that the contractor must meet. Hopefully, as buying commands become more sophisticated, Cpk's will be called out in the contracts. Until that time you have your work cut out for you!

#### Example #4

This example is for an DCMC in-plant or staff specialist

ABC Corp. is producing one-inch diameter shafts for transmissions. The contractor knows that some of the production is out of tolerance. However, he is hoping that they will be accepted through the Material Review Board (MRB) as "use as is". You ask the contractor for a set of data to review the process. The contractor is reluctant but provides you the data that produced the last 20 point entries on his process control chart. These data are actual measurements of 100 shafts taken in subgroups of 5. The specification is 1.06" +/- 0.06";

Therefore the Lower Spec Limit (LSL) = 1.000"

the Upper Spec Limit (USL) = 1.120"

#### Actual Automated Data Set:

1	1.094	1.061	1.111	1.116	1.085	1.097	11/30	0700
2	1.091	1.100	1.083	1.052	1.103	1.118	11/30	0730
3	1.085	1.090	1.072	1.100	1.092	1.070	11/30	0800
4	1.110	1.133	1.134	1.075	1.107	1.102	11/30	0830
5	1.110	1.127	1.121	1.086	1.093	1.125	11/30	0900
6	1.115	1.105	1.115	1.097	1.150	1.107	11/30	0930
7	1.087	1.079	1.104	1.049	1.129	1.073	11/30	1000
8	1.106	1.104	1.142	1.099	1.095	1.088	11/30	1030
9	1.086	1.076	1.095	1.091	1.070	1.098	11/30	1100
10	1.120	1.118	1.132	1.142	1.129	1.073	11/30	1130
11	1.117	1.102	1.093	1.141	1.136	1.111	11/30	1200
12	1.113	1.063	1.130	1.136	1.116	1.118	11/30	1230
13	1.108	1.092	1.074	1.104	1.147	1.125	11/30	1300
14	1.081	1.080	1.106	1.067	1.074	1.080	11/30	1330
15	1.106	1.083	1.067	1.111	1.128	1.142	11/30	1400
16	1.112	1.063	1.108	1.126	1.144	1.120	11/30	1430
17	1.106	1.136	1.127	1.047	1.128	1.092	11/30	1500
18	1.118	1.133	1.111	1.102	1.097	1.147	11/30	1530
19	1.085	1.068	1.108	1.097	1.073	1.079	11/30	1600
20	1.102	1.085	1.139	1.137	1.077	1.074	11/30	1630

Field 1 is Sample Number

Field 2 is the average of the 5 values (plot point)

Field 3 is Reading #1

Field 4 is Reading #2

Field 5 is Reading #3

Field 6 is Reading #4

Field 7 is Reading #5

Field 8 is a 1997 Date

Field 9 is Time

The buying command has informed us that the larger dimension up to 1.160 will fit and do not seem to affect form, fit or function, at least in the short term. They also inform us that there are many more contracts coming for these transmission shafts. We are told that since the drawing tolerances represent the optimal situation, they will not be changed and that future out of tolerance shaft will not be accepted via MRB. How do we proceed under these conditions?

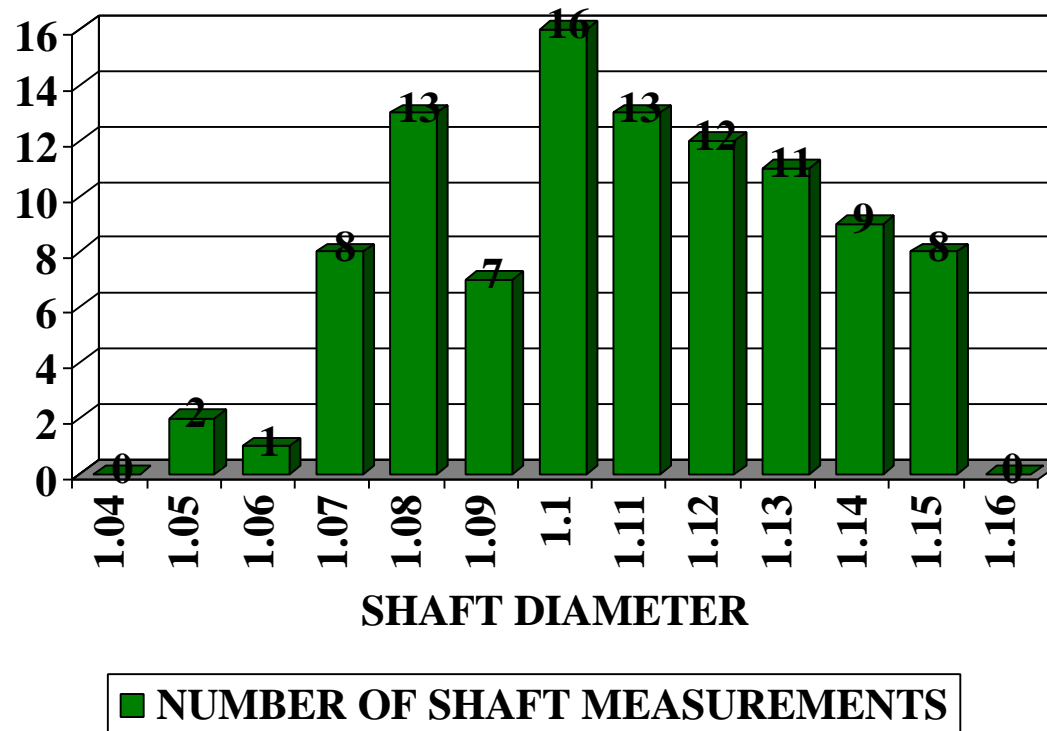
#### **QUESTIONS:**

##### **What should be done?**

1. Make a histogram of all the measurements.
2. Calculate the mean/average of the data.
3. Calculate then standard deviation.
4. Interpret the Contractor's Xbar and R charts.
5. What do these charts tell us?
6. Calculate the Cp and Cpk of the process.
7. What % is out of tolerance now?
8. If the process mean was shifted for an optimum condition, what % would then be out of tolerance.  
(Need to re-calculate Cpk)
9. Should a CIO be written? What would it say?

# EXERCISE #4

## HISTOGRAM



# EXAMPLE #4

If made properly, the Histogram can show about 28% of the actual readings out of tolerance.

Range of the 1st reading is  $1.116 - 1.061 = .055$

$$\bar{R} = \frac{\text{Total Ranges}}{\text{Total \# Sets}} = \frac{1.168}{20} = .0584$$

$$\bar{X} = \frac{\text{Total of Xs}}{\text{Total \# Sets}} = \frac{22.059}{20} = 1.10295$$

$$UCL_x = \bar{X} + A_2 \bar{R} = 1.10295 + (.577)(.0584) = 1.13663$$

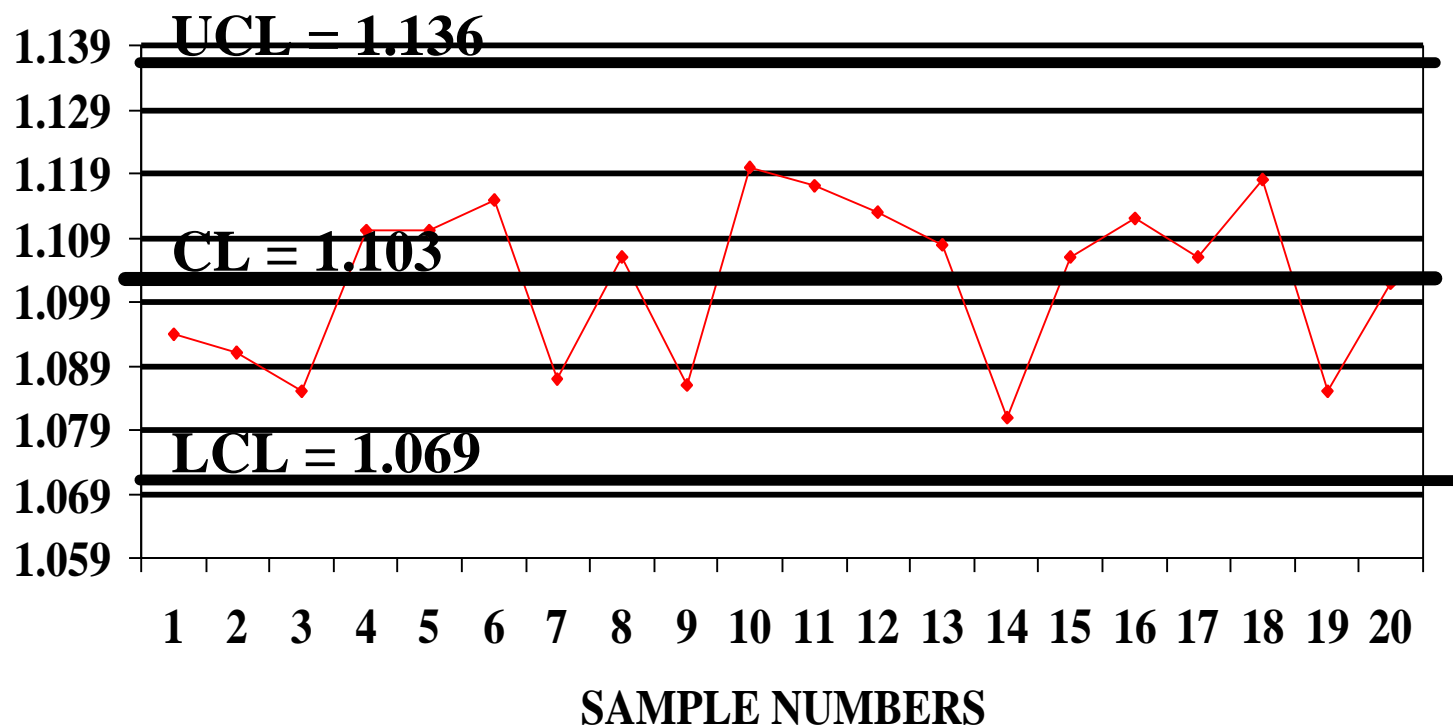
$$LCL_x = \bar{X} - A_2 \bar{R} = 1.10295 - (.577)(.0584) = 1.06926$$

$$UCL_r = D_4 \bar{R} = (2.114)(.0584) = .123486$$

$$LCL_r = D_3 \bar{R} = (0)(.0584) = 0.0$$

# EXAMPLE #4

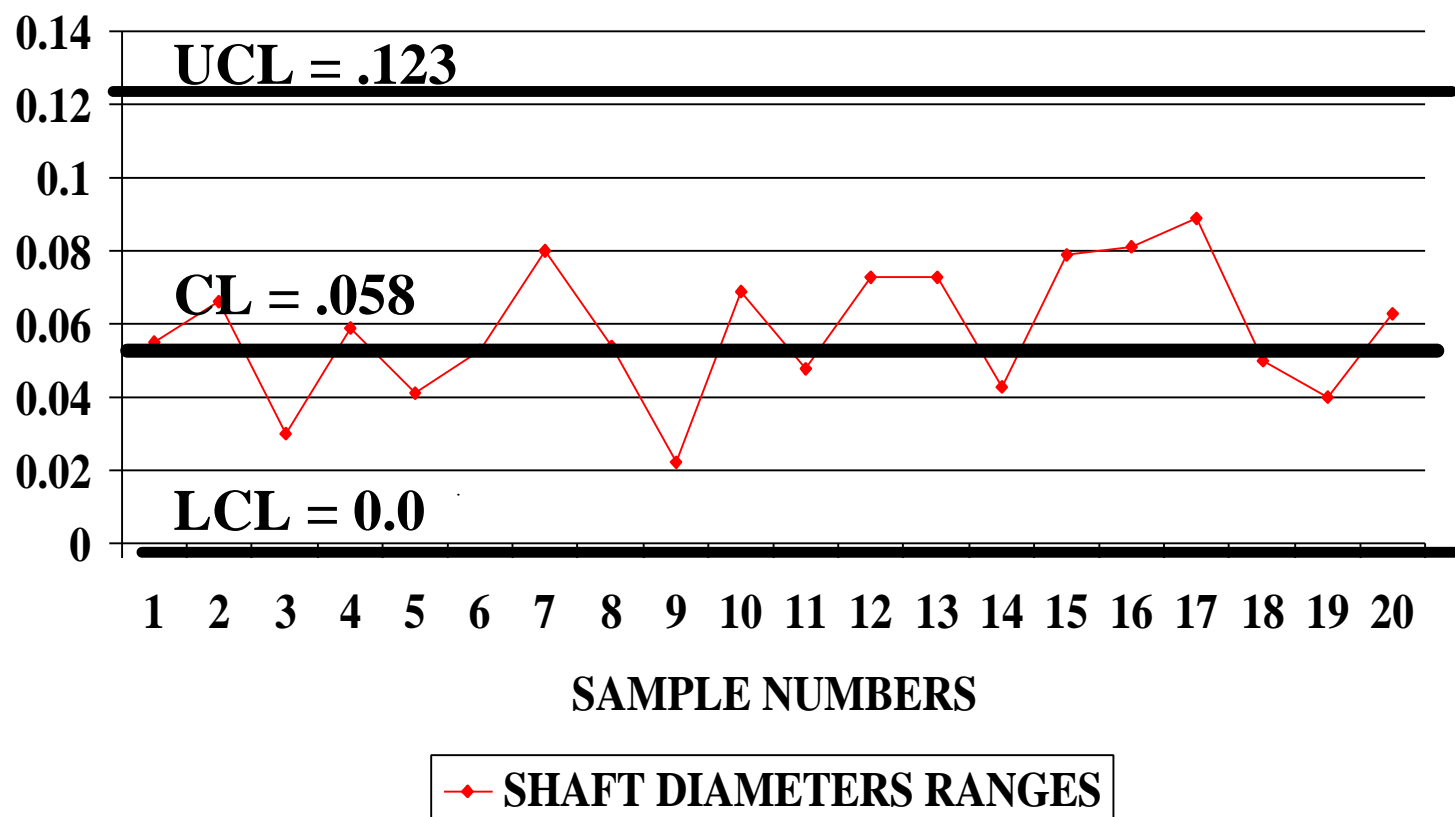
## X BAR CHART



—♦— SHAFT DIAMETERS AVG

# EXAMPLE #4

## R BAR CHART



# EXAMPLE #4

## Process Capability & Performance

$$\hat{\sigma} = \frac{\bar{R}}{d_2} = \frac{.0584}{2.326} = .025107 \quad \text{note: } d_2 = 2.326 \text{ for } n = 5$$

$$C_p = \frac{\text{TOT TOL}}{6 \sigma} = \frac{.12}{6(.025107)} = .796575$$

Normally you would not calculate Cpk, but because of the question about shifting the mean...

$$C_{pk} = \text{Min}(C_{pl}, C_{pu}) = C_{pu} = \frac{\text{USL} - \bar{X}}{3\sigma} = \frac{.017505}{.075321} = .2264$$

Where: Cpl is Cp lower      Cpk is always the minimum of the  
Cpu is Cp upper      two values, therefore Cpk = .2264

## SUMMARY

What did the histogram tell you? It should have told you that the process was not centered around 1.06" but something much higher. Calculating the mean taking all the values =  $22.059/20 = 1.103$ . Looking at the contractor's Xbar control chart we see that the process is in control, and although no point has gone beyond 1.120 many individual values are beyond this upper specification limit. Looking at the Range chart variance per sample is relatively large with a Rbar of .0584. The Cp value of .8 means 2.4 standard deviations are covered by the spread or a % defective of 1.62 (.82% out of tolerance on each side) if the process were centered on the Mean Tolerance Dimension (MTD). However, this not centered there. The Cpk of .2264 on the high side shows a percent defective of 24.83% When measuring the low side we get a percent defective of less than .0001%. So you can see that if we center the process, making the Cp = Cpk = .8, we can reduce the percent defective 15 fold, from 24.83% to 1.62%. A CIO should be issued explaining how the current process can be improved.

### Example #5

This example is for a DCMC in-plant or staff specialist

A contractor was maintaining records of final inspection. The final inspection of an electronic device called for checking many characteristics. Although the report form used in final inspection listed some 20 possible causes for rejection, most of these rejections were based on 4 or 5 of these causes. The contractor has been running about 31% defective product on his final inspection.

The contractor has provided you with his data for Jan 6,7 and 8. The use of an attribute "p" control chart is most effective when samples are large, that is greater than 50, or when the expected number of defective units per sample are "4" or more. Also note that out of control conditions can mean that quality is poor, or that the contractor has a faulty inspection system. It is worth investigating to:

1. Ascertain assignable causes
2. Ascertain variation of the process
3. Ascertain how to improve the quality levels of the process

Company Data Sheet:

1	1/6/97	200	72	404
2	1/6/97	100	53	404
3	1/6/97	300	133	404
4	1/6/97	100	19	404
5	1/6/97	300	136	404
6	1/6/97	200	82	404
7	1/7/97	300	132	404
8	1/7/97	200	55	404
9	1/7/97	200	64	404
10	1/7/97	300	129	404
11	1/7/97	300	79	404
12	1/7/97	200	72	404
13	1/8/98	200	47	404
14	1/8/97	300	78	404
15	1/8/97	100	38	404

Field 1 is Record Number

Field 2 is Date

Field 3 is Number inspected

Field 4 is Number defective

Field 5 is Work center Number

## QUESTIONS:

### What should be done?

1. Make a 'p' control chart.
2. What are the fractional defectives?
3. Is the contractor's process in control?
4. What did you find out?
5. Make a trend chart. Is there a trend? Does it matter?
6. What action should be taken?

### Fractional Defective Data Chart:

NO.	Date	No. Inspct	No. Deft	Fract Deftve
1.	1/6/97	200	72	0.36
2.	1/6/97	100	53	0.53
3.	1/6/97	300	133	0.44
4.	1/6/97	100	19	0.19
5.	1/6/97	300	136	0.45
6.	1/6/97	200	82	0.41
7.	1/7/97	300	132	0.44
8.	1/7/97	200	55	0.28
9.	1/7/97	200	64	0.32
10.	1/7/97	300	129	0.43
11.	1/7/97	300	79	0.26
12.	1/7/98	200	72	0.36
13.	1/8/97	200	47	0.24
14.	1/8/97	300	78	0.26
15.	1/8/98	100	38	0.38

# EXAMPLE #5

## 'P' CHART FORMULAS

$$\text{Center Line CL} = \bar{p} \quad \bar{p} = \frac{\text{Number of Nonconforming Units}}{\text{Total Number of Units inspected}}$$

$$\text{Upper Control Limit} = \text{UCL}_p = \bar{p} + 3 \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$$

$$\text{Lower Control Limit} = \text{LCL}_p = \bar{p} - 3 \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$$

$$\text{EG., CL} = \frac{1189}{3300} = .3603 = .36 = \bar{p}$$

# EXAMPLE #5

## 'P' CHART FORMULAS CONTINUED

$$\begin{aligned}\text{Upper Control Limit} = \text{UCL}_p &= .36 + 3 \sqrt{\frac{.36(1 - .36)}{200}} = .462 \\ \text{Lower Control Limit} = \text{LCL}_p &= .36 - 3 \sqrt{\frac{.36(1 - .36)}{200}} = .258\end{aligned}$$

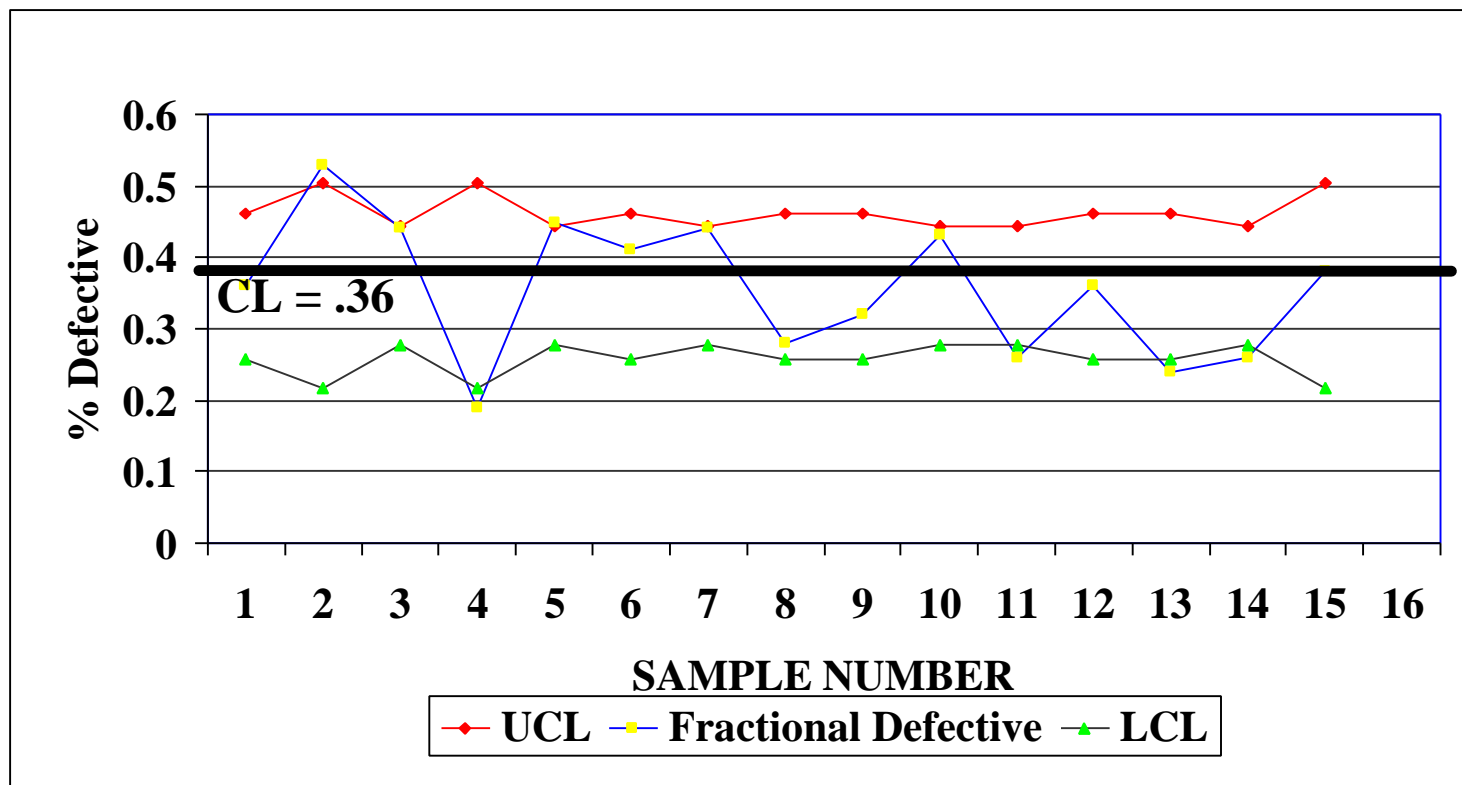
Unfortunately, new limits must be calculated for every new "n" unless all "n's" are within 25% of each other.

Fortunately in this problem, there are only 3 different n's namely: 100, 200 and 300.

Note the out of control points: 2 above at points 2 & 5, and 3 below at points 4, 13 & 14.

# EXAMPLE #5

## 'P' CHART



## SUMMARY

What did the control chart tell you? It should have told you that there appears to be numerous special/assignable causes present in the process. Elimination of these special causes is paramount before this process will ever be in-control. Then, and only then can we start to worry about the common causes. This is also the major reason that trend charts under these circumstances will not tell us very much. Assignable causes will skew any trend chart whenever they occur. This process should be continually monitored. It would seem from the data provided, that even after the assignable causes are eliminated, much more work will still be needed to reduce common causes. Please also note that when dealing with attribute data,  $C_p$  and  $C_{pk}$  values can not realistically be calculated. A CIO should be issued pointing out that there are special/assignable causes affecting this process. Identification of these causes can only improve this process.

### Example #6

This example is for a DCMC in-plant or staff specialist

A contractor was maintaining records of a final assembly process. The inspection tested different alignments of critical parts. The contractor has provided you with his data for Feb 6,7 and 8. The use of an attribute "c" control chart is most effective when circumstances dictate a significant number of defects on a single item; e.g., rivets on an aircraft wing or the number of nonconformities of all types observed in the inspection of sub assemblies and final assemblies of many complex items. Below is a Company Data Sheet. The numbers seem to indicate either a degradation of quality or an increase in strictness on the part of the inspector.

Company Data Sheet:

1	2/6/97	101	7	501
2	2/6/97	102	6	501
3	2/6/97	103	6	501
4	2/6/97	104	7	501
5	2/6/97	105	4	501
6	2/6/97	106	7	501
7	2/6/97	107	8	501
8	2/6/97	108	12	501
9	2/6/97	109	9	501
10	2/6/97	110	9	501
11	2/6/97	111	8	501
12	2/6/97	112	5	501
13	2/6/98	113	5	501
14	2/6/97	114	9	501
15	2/6/97	115	8	501
16	2/6/97	116	15	501
17	2/6/97	117	6	501
18	2/7/97	118	4	501
19	2/7/97	119	13	501
20	2/7/97	120	7	501
21	2/7/97	121	8	501
22	2/7/97	122	15	501
23	2/7/97	123	6	501
24	2/7/97	124	6	501
25	2/7/97	125	10	501

Field 1 is Record Number

Field 2 is Date

Field 3 is the unit number

Field 4 is Number of defective

Field 5 is the Inspector Number

Company Data sheet:

26	2/7/97	126	7	501
27	2/7/97	127	13	501
28	2/7/97	128	4	501
29	2/7/97	129	5	501
30	2/7/97	130	9	501
31	2/7/97	131	3	501
32	2/7/97	132	4	501
33	2/7/97	133	6	501
34	2/7/97	134	7	501
35	2/7/97	135	14	501
36	2/7/97	136	18	501
37	2/7/97	137	11	501
38	2/8/98	138	11	501
39	2/8/97	139	11	501
40	2/8/97	140	8	501
41	2/8/97	141	10	501
42	2/8/97	142	8	501
43	2/8/97	143	7	501
44	2/8/97	144	16	501
45	2/8/97	145	13	501
46	2/8/97	146	12	501
47	2/8/97	147	9	501
48	2/8/97	148	11	501
49	2/8/97	149	11	501
50	2/8/97	150	8	501

Field 1 is Record Number

Field 2 is Date

Field 3 is the unit number

Field 4 is Number of defective

Field 5 is the Inspector Number

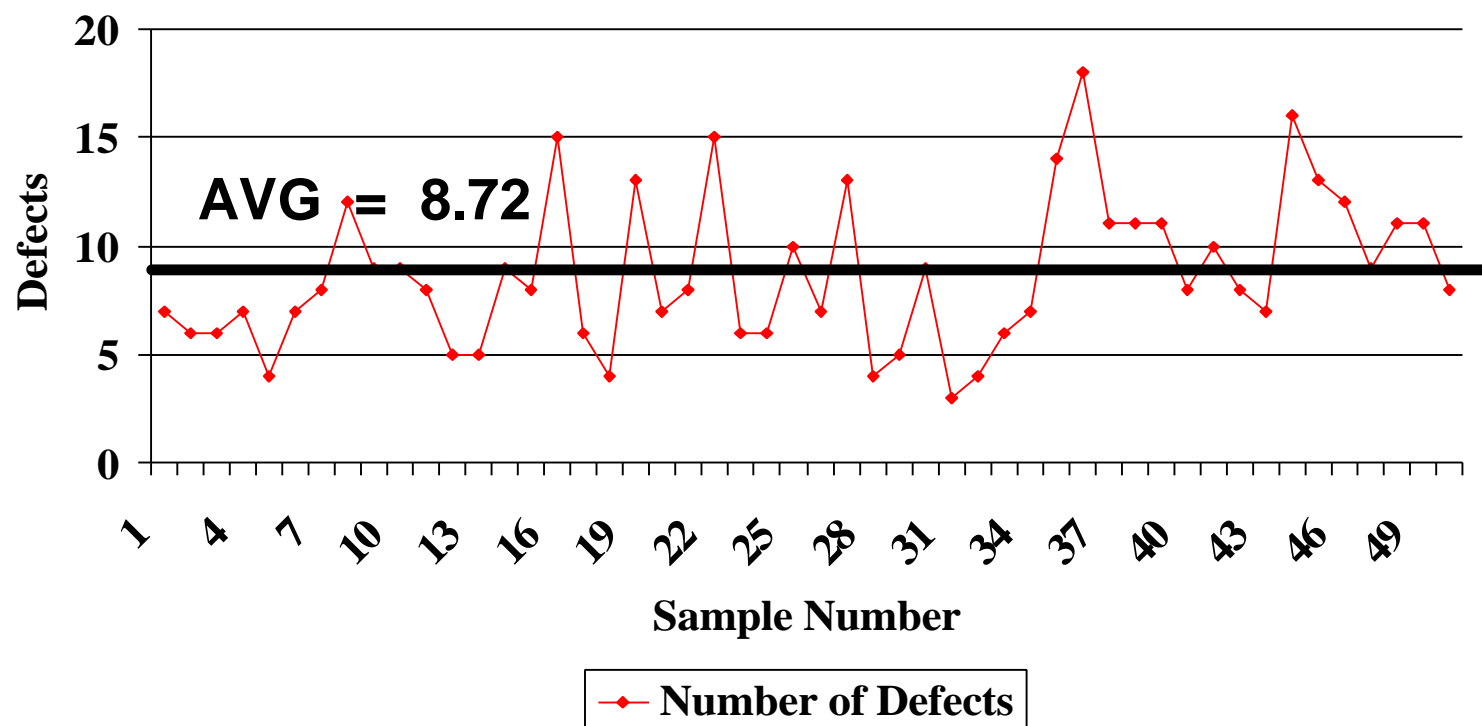
**QUESTIONS:**

**What should be done?**

1. Ascertain assignable causes
2. Ascertain variation of the process
3. Ascertain how to improve the quality levels of the process.
4. Make a 'c' control chart.
5. What is the average number of defects?
6. Is the contractor's process in control?
7. What did you find out?
8. Make a trend chart. Is there a trend? Does it matter?
9. What action, if any, should be taken?

# EXAMPLE #6

## TREND CHART



# EXAMPLE #6

## 'C' CHART

$$\text{Center Line} = \text{CL} = \bar{c} = \frac{\text{Total Number of Defects}}{\text{Total Number of Units}}$$

$$\bar{c} = 436/50 = 8.72$$

$$\text{UCL} = \bar{c} + 3 \sqrt{\bar{c}} \quad \text{LCL} = \bar{c} - 3 \sqrt{\bar{c}}$$

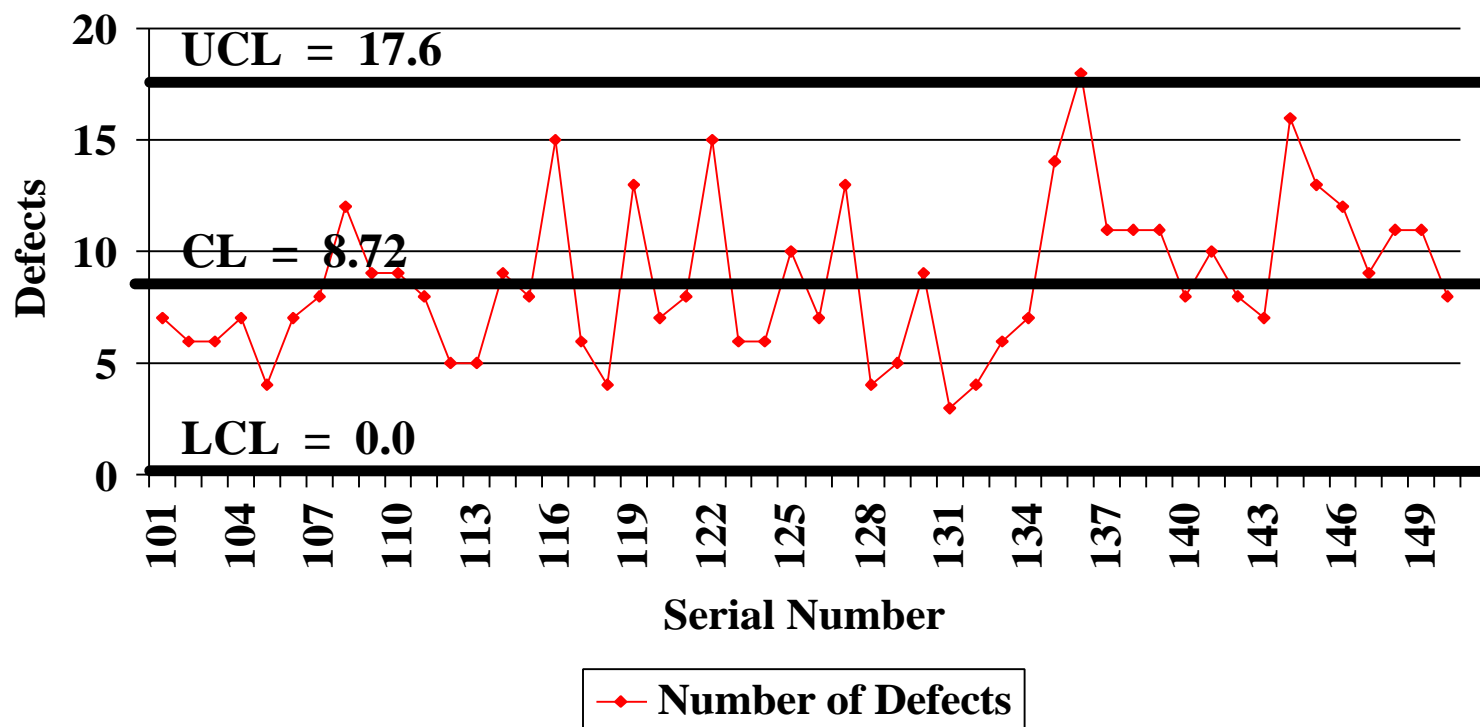
$$\text{UCL} = 8.72 + 3 \sqrt{(2.953)} = 17.58$$

$$\text{LCL} = 8.72 - 3 \sqrt{(2.953)} = -.13 \text{ therefore} = 0.0$$

**NOTE:** There is one out of control point.

# EXAMPLE #6

## 'C' CHART



## SUMMARY

What did the control chart tell you? It should have told you that there appears to be a special/assignable cause present in the process. Elimination of this special cause is paramount before this process will ever be in-control. Then, and only then can we start to worry about the common causes. The trend chart seems to confirm your suspicions that either the process is getting worse or the inspectors have become more strict. Was there any indication that the company inspector changed his criteria of inspection? If not, a degradation of the process seems to be occurring. After correcting the special cause, identification of exactly what defects are occurring would be in order. Then, pareto charts etc. This process should be continually monitored. A CIO should probably be issued pointing out that there is/are special/assignable cause(s) affecting this process.

### Example #7

This example is for a DCMC in-plant or staff specialist

A contractor was maintaining records of an assembly process. The inspection was an in-process audit of painted items before moving to the next production center. The U-Chart is particularly effective when the number of defects possible on a unit is large, there are a different number of multiple units inspected, and the percentage for any single defect is small.

Review of the data revealed that the defects varied from in control to out of control conditions depending upon the shift doing the inspection. Several factors should be investigated:

1. Which shift is the production from?
2. What kinds of defects are being found since that data was not provided?
3. Is the strictness of the inspector a factor and are there defined inspector instructions?

Company Supplied Data Sheet:

1	2/1/97	D	13	6
2	2/1/97	S	12	4
3	2/1/97	G	7	3
4	2/2/97	D	19	6
5	2/2/97	S	14	5
6	2/2/97	G	9	2
7	2/3/97	D	18	6
8	2/3/97	S	13	4
9	2/3/97	G	6	2
10	2/4/97	D	24	6
11	2/4/97	S	15	5
12	2/4/97	G	6	3
13	2/5/97	D	16	7
14	2/5/97	S	11	4
15	2/5/97	G	20	3
16	2/6/97	D	16	4
17	2/6/97	S	29	4
18	2/6/97	G	3	2
19	2/7/97	D	21	6
20	2/7/97	S	20	4
21	2/7/97	G	2	2
22	2/8/97	D	14	3
23	2/8/97	S	10	2
24	2/8/97	G	3	1
TOT			321	94

Field 1 is Record Number

Field 2 is the Date

Field 3 is the shift designator

Field 4 is Number of defects

Field 5 is the Units inspected

### Reading Extracted Data from Data Set

1	2/1/97	D	13	6	2.2
2	2/1/97	S	12	4	3.0
3	2/1/97	G	7	3	2.3
4	2/2/97	D	19	6	3.2
5	2/2/97	S	14	5	2.8
6	2/2/97	G	9	2	4.5
7	2/3/97	D	18	6	3.0
8	2/3/97	S	13	4	3.3
9	2/3/97	G	6	2	3.0
10	2/4/97	D	24	6	4.0
11	2/4/97	S	15	5	3.0
12	2/4/97	G	6	3	2.0
13	2/5/97	D	16	7	2.3
14	2/5/97	S	11	4	2.8
15	2/5/97	G	20	3	6.7
16	2/6/97	D	16	4	4.0
17	2/6/97	S	29	4	7.3
18	2/6/97	G	3	2	1.5
19	2/7/97	D	21	6	3.5
20	2/7/97	S	20	4	5.0
21	2/7/97	G	2	2	1.0
22	2/8/97	D	14	3	4.7
23	2/8/97	S	10	2	5.0
24	2/8/97	G	3	1	3.0
TOT			321	94	3.415

Column 1 is the record number

Column 2 is the Date

Column 3 is the shift designator

Column 4 is Number of defects

Column 5 is the Units Inspected

Column 6 is the number of defects per unit

### QUESTIONS:

#### What should be done?

1. Ascertain assignable causes.
2. Ascertain variation of the process.
3. Ascertain how to improve the quality levels of the Process.
4. Make a 'u' control chart.
5. What is the average number of defects?
6. Did you make a Pareto chart by Day?
7. Did you make a Pareto chart by Shift? Number Defects, Average Defects?
8. Is the contractor's process in control?
9. What did you find out?
10. Make a trend chart. Is there a trend? Does it matter?
11. What action should be taken?

## EXAMPLE #7

**NOTE:** Just as in the 'p' chart, the upper and lower control limits must be re-calculated for each different number of units inspected. The formulas are as follows:

$$CL = \frac{\text{Total Defects}}{\text{Total Units Insp}} = \frac{321}{94} = 3.415 = \bar{u}$$

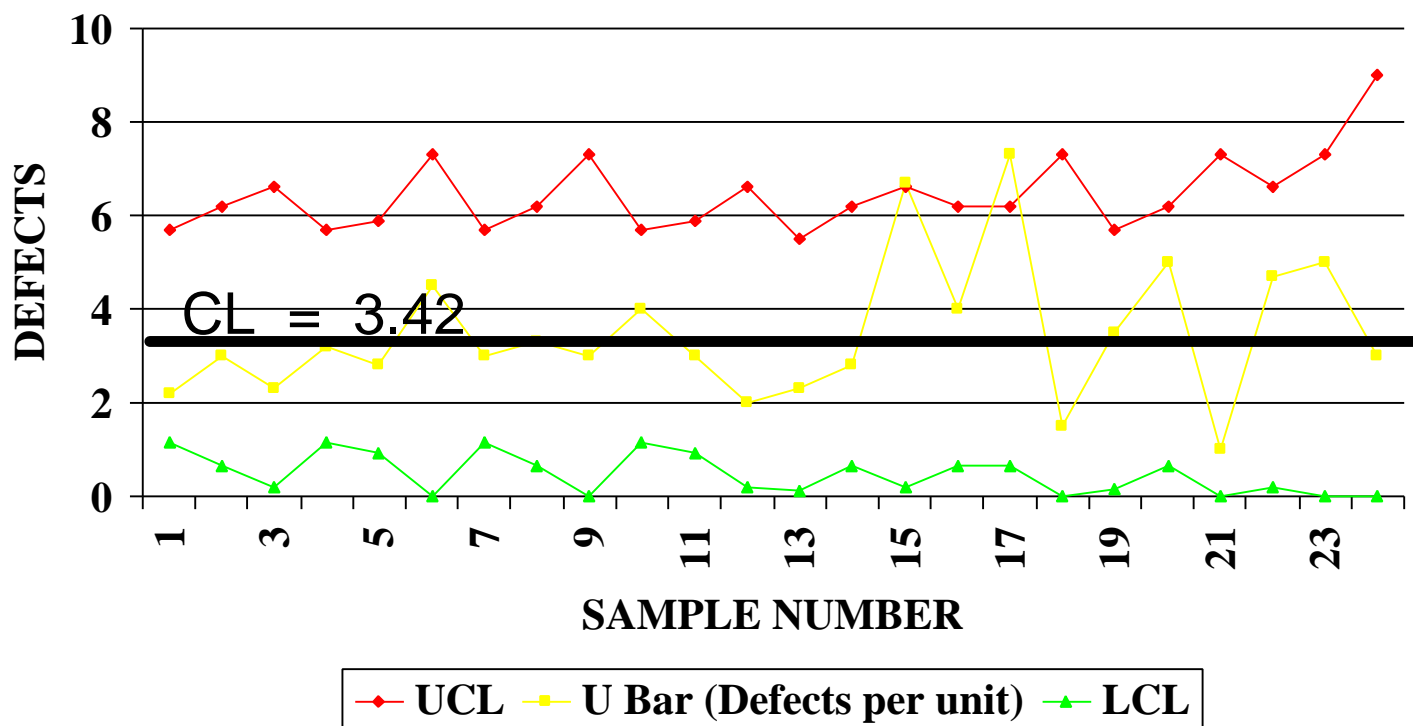
FOR  $n = 4$

$$UCL = \bar{u} + 3 \frac{\sqrt{\bar{u}}}{\sqrt{n}} = 3.415 + 3 \frac{\sqrt{3.415}}{\sqrt{4}} = 6.187$$

$$LCL = \bar{u} - 3 \frac{\sqrt{\bar{u}}}{\sqrt{n}} = 3.415 - 3 \frac{\sqrt{3.415}}{\sqrt{4}} = 0.643$$

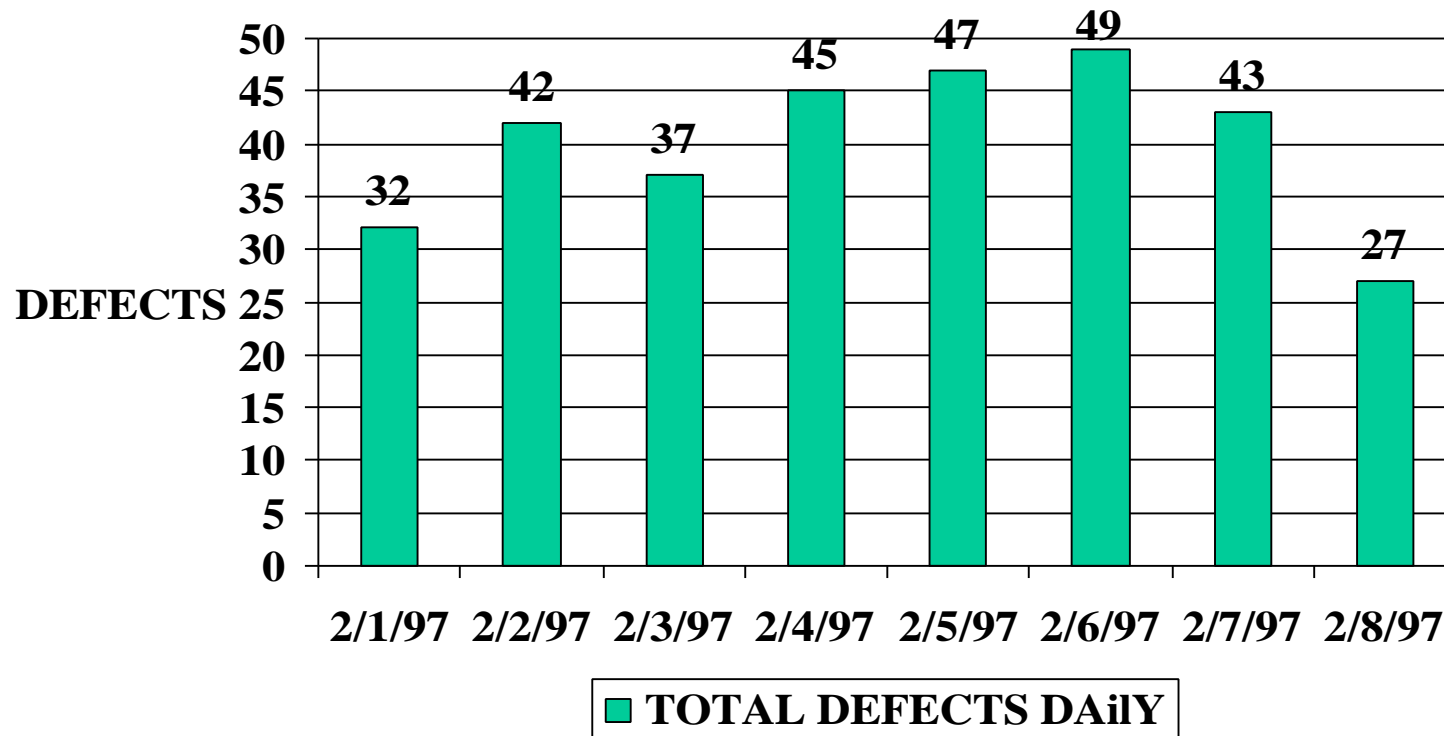
# EXAMPLE #7

## 'U' CHART



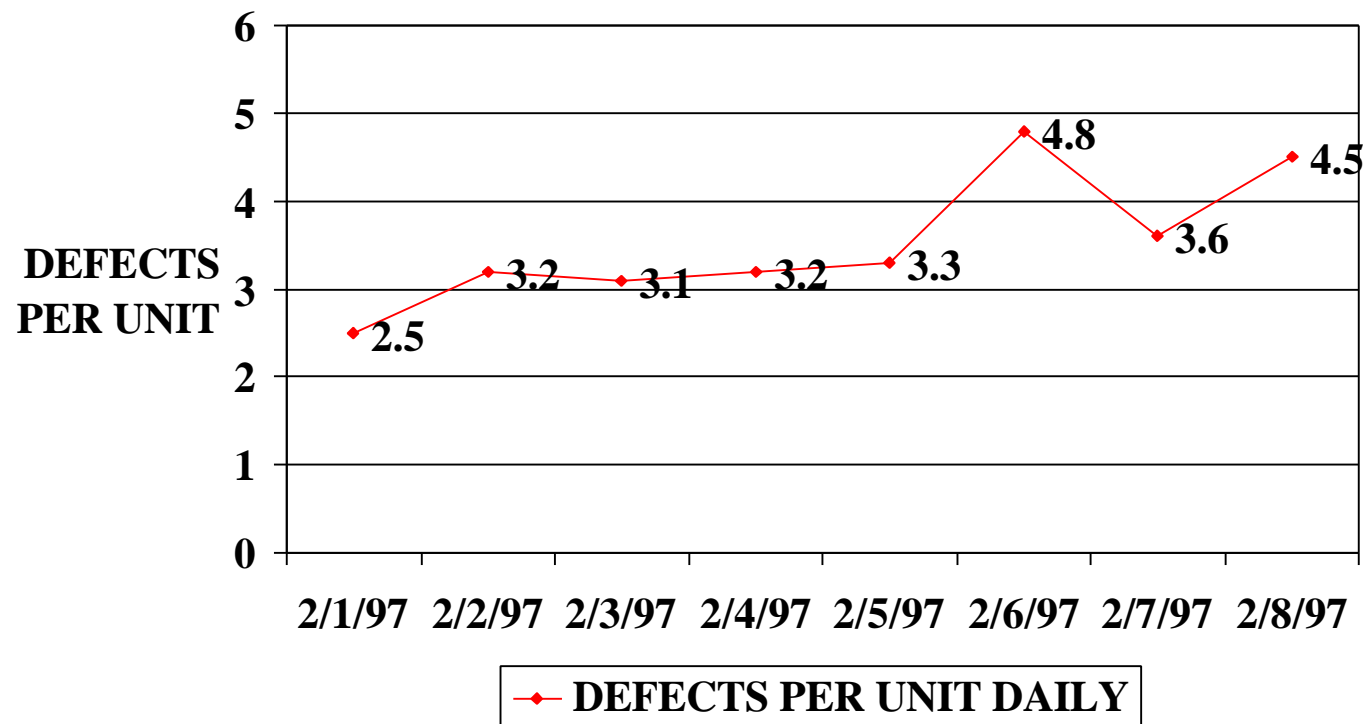
# EXAMPLE #7

## BAR CHART BY DAY



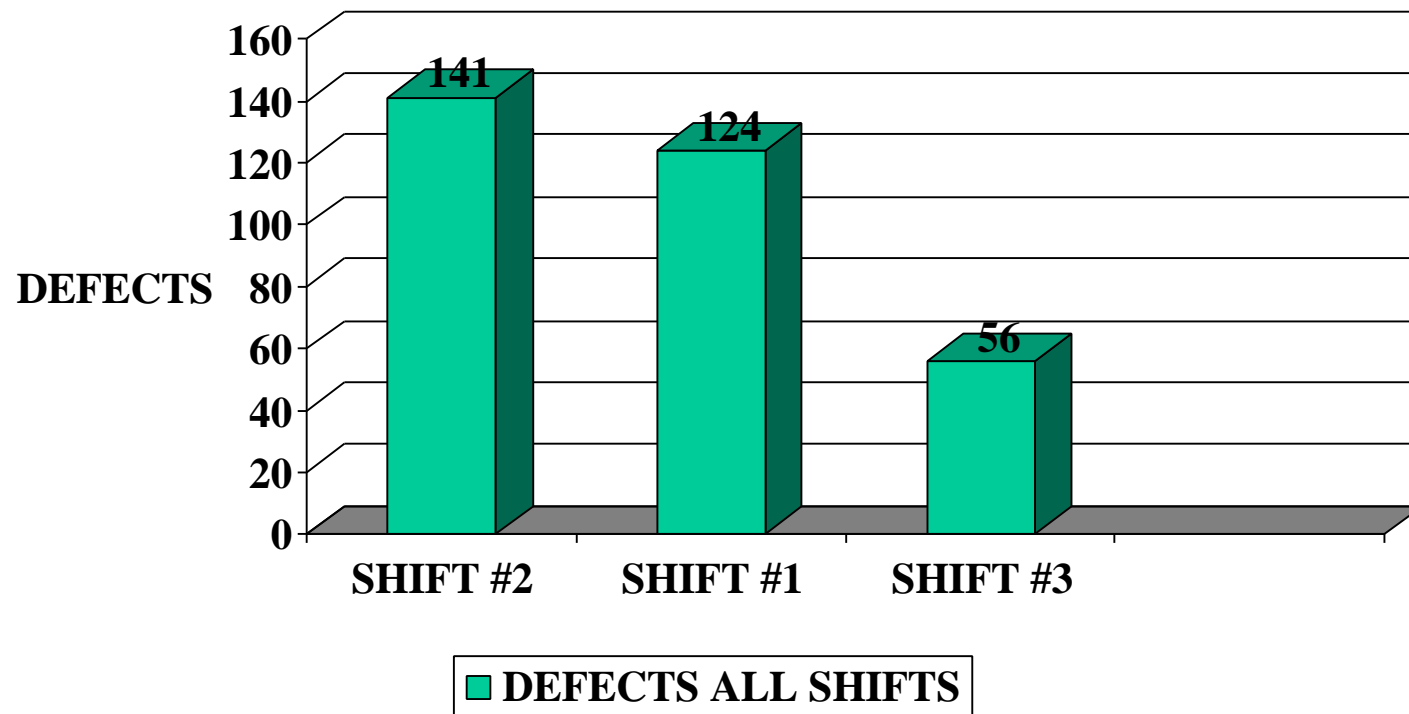
# EXAMPLE #7

## TREND CHART BY DAY



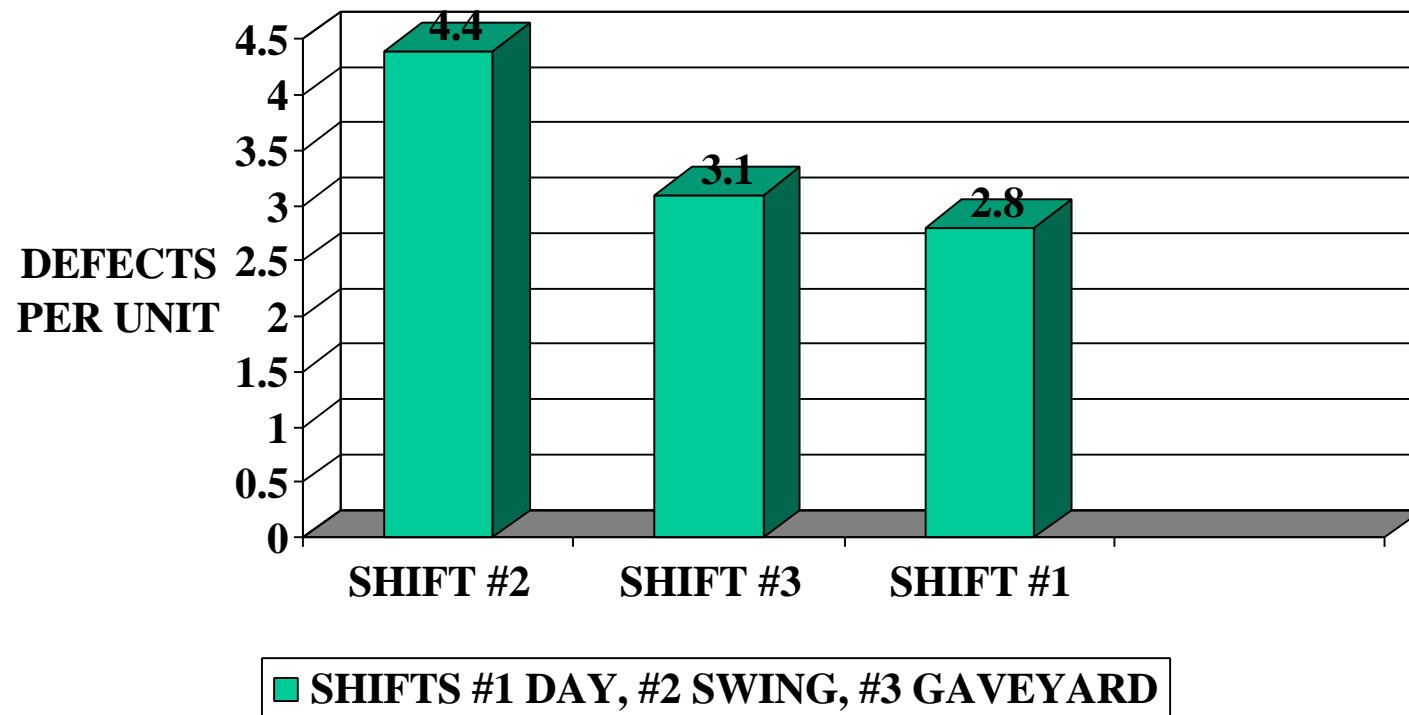
# EXAMPLE #7

## PARETO BY SHIFT



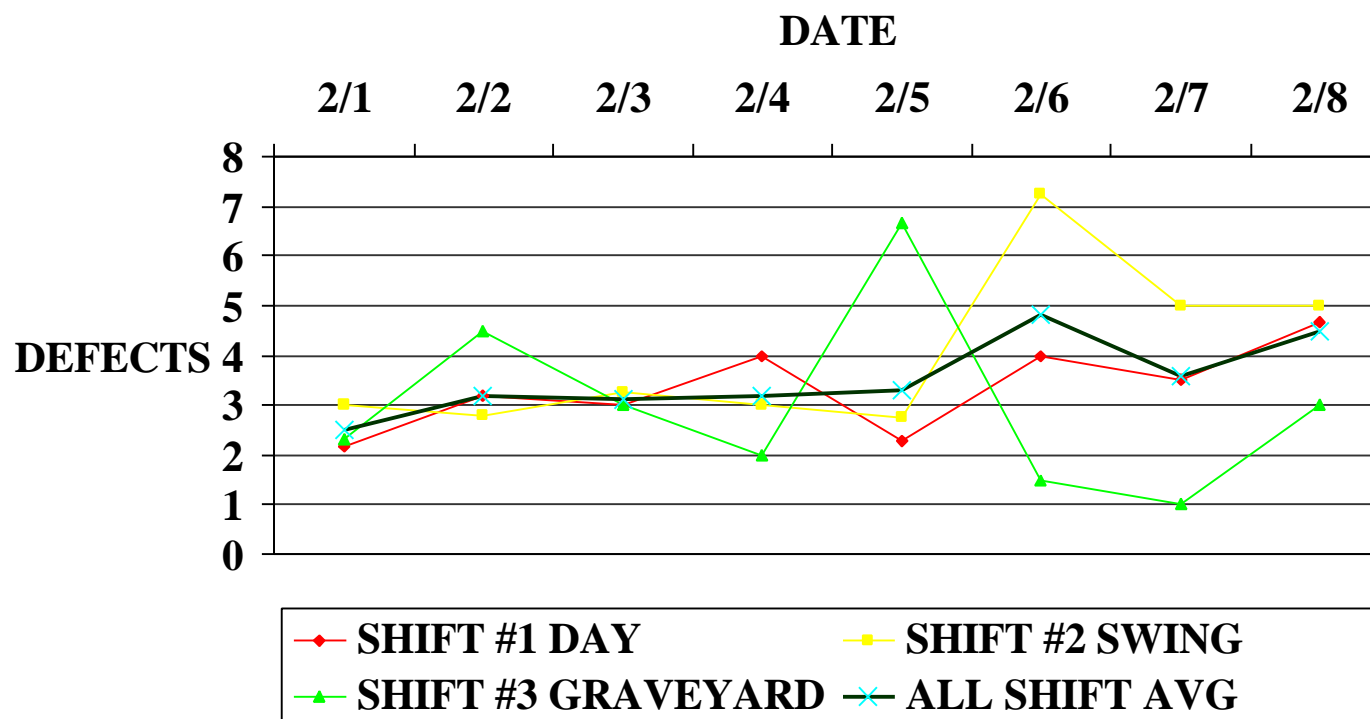
# EXAMPLE #7

## DEFECTS PER UNIT BY SHIFT



# EXAMPLE #7

## Nonconformities by Shift by day



## SUMMARY

The 'U' Chart should have told you that the process is out of control. The trend chart also should have told you that the process seems to be getting worse. The last 3 days showed the highest defects per unit. The non-conformities by shift chart is inconclusive because the number of units is a variable. The Pareto chart 'Defects By Shift' really tells us nothing but, the Pareto chart 'Defects Per Unit By Shift' seems to show that the Swing shift is definitely producing more defects per unit. Investigation of the following should be made:

1. Why more defects per unit is increasing.
2. Why the 2<sup>nd</sup> shift is producing more defects per unit.
3. What special/assignable causes occurred on the 5<sup>th</sup> and 6<sup>th</sup> of February.

Once these questions are finally answered then, and only then, can the investigation of this process reach conclusion.

### Example #8

This example is for a DCMC in-plant or staff specialist

A plant process assembles transmissions. Each day a random sample lot of 200 are drawn and inspected. This is not the contractor's final inspection however, it does involve an over-all functional test of the device.

Review of the data reveals that on December 15<sup>th</sup>, (sample #5), the number of defectives was extremely high. Also, it was noted that the range of number of defectives found varied greatly from day to day. The kinds of defects being found were not provided. What should be investigated? Note that an attribute 'np' chart is the most effective way of monitoring a process when the sample size is large (greater than 50) and the same number of samples are always taken, or at least lie within 25% of each other. For example, if you took 200 units on day and 180 the next, you would still be able to use an "np" chart since 180 and 200 are well within 25% of one another. Let us first look at the "np" chart and see what it tells us.

Company Supplied Data Sheet:

1	12/11/97	200	23	770
2	12/12/97	200	15	770
3	12/13/97	200	17	770
4	12/14/97	200	15	770
5	12/15/97	200	41	770
6	12/16/97	200	0	770
7	12/17/97	200	25	770
8	12/18/97	200	31	770
9	12/19/97	200	29	770
10	12/20/97	200	0	770
11	12/21/97	200	8	770
12	12/22/97	200	16	770

Column 1 is the record number  
Column 2 is the Date  
Column 3 is the sample size  
Column 4 is Number of defectives  
Column 5 is the Units Inspected  
Column 6 is the work center number

### **QUESTIONS:**

**What should be done?**

1. Is the process in control?
2. Are there special causes present?
- 3 If so, do we know what they are?
4. What are the **defects** that are being found?
5. Can we find out?
6. Are the same inspectors always inspecting?
7. If you found out the types of defects, is it necessary to put them on a Pareto chart?
8. What action should be taken?

### **ANSWERS:**

1. The inspection station had 31 different possible defects that could cause the unit to be defective.
2. The contractor has been working the problem and has narrowed the problem down to 9 major defects that were causing the defectives.
3. Separate charts were being developed to track each of the nine major defects.

## EXAMPLE #8

**NOTE:** Just as in the 'c' chart, the upper and lower control limits remain constant throughout the 'np' chart. The formulas are as follows:

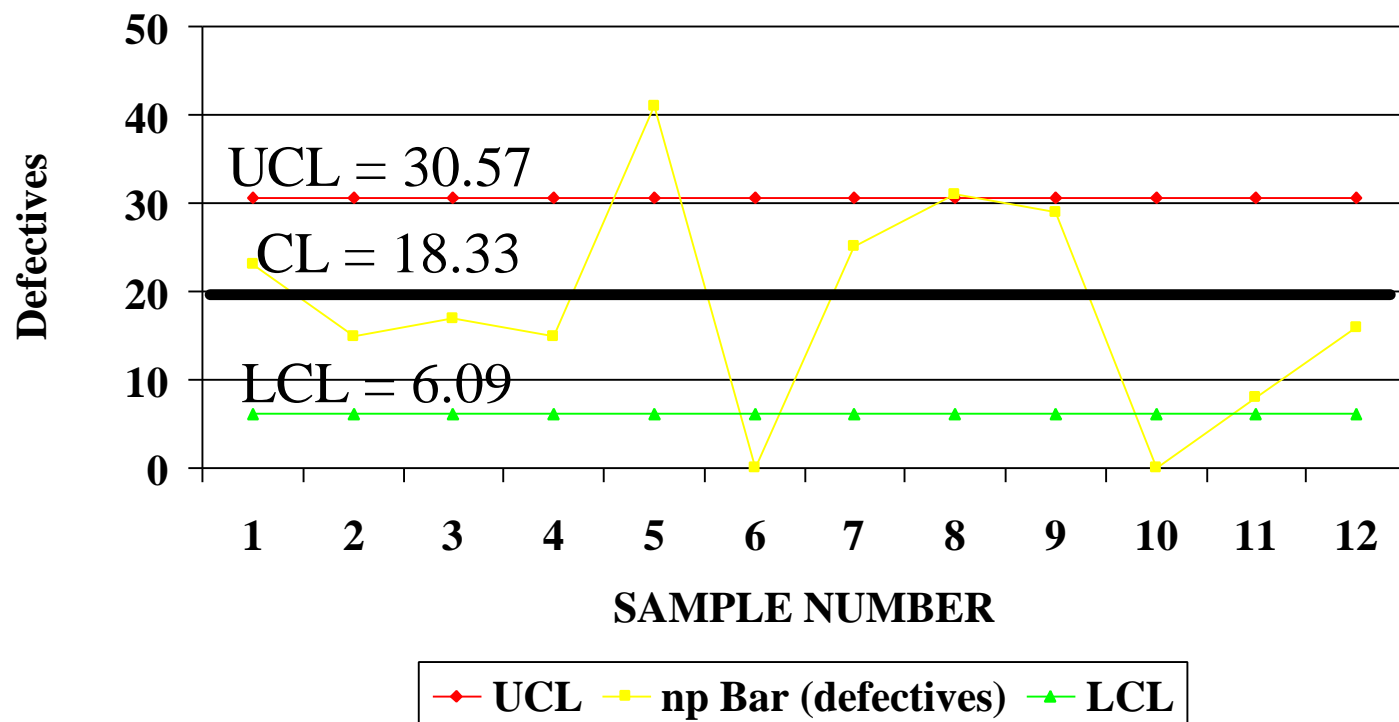
$$\text{CL} = n\bar{p} = \frac{\text{Total Defectives}}{\text{Total Units Insp}} = \frac{220}{2400} \times 200 = 18.33$$

$$\text{UCL} = n\bar{p} + 3 \sqrt{n\bar{p}(1 - \bar{p})} = 18.33 + 3(4.08) = 30.57$$

$$\text{LCL} = n\bar{p} - 3 \sqrt{n\bar{p}(1 - \bar{p})} = 18.33 - 3(4.08) = 6.09$$

# EXAMPLE #8

## 'np' CHART



## **SUMMARY**

Your 'np' chart should have showed you that the process is completely out of control. Although the contractor seems to be headed in the right direction on the defects problem, the out of control conditions/special assignable causes were not addressed. Until the contractor can identify what these assignable causes are, he/she will be unable to maintain an in-control process. Investigation must be made to identify these causes. Once addressed, The defect analysis now being performed by the contractor will help provide a better process.

### Example #9

This example is for a DCMC in-plant or staff specialist

After flowcharting a contractor's operations and discussions with engineering and technical staff, John, the in-plant government representative, has determined that the coating operation is a critical process that needs to be monitored. The measurement point of the coating process is the weight of the coating after it has been applied to the parts. This characteristic will provide the best feedback on the processes' performance.

John has decided that since no variation can be detected from piece to piece within a subgroup, he will have to utilize individual readings to track the process. One part every 2 hours has been selected and the resultant data recorded on the sheet below. The Individual 'X' and Moving Range chart is used to monitor processes in situations where only one measurement/reading can be taken at any one time (a subgroup size 'n' of 2 or more can not be obtained). The coating specifications are: Upper Spec limit 145 mg/ft<sup>2</sup>

Lower Spec Limit 125 mg/ft<sup>2</sup>

Mean Tolerance Dimension 135 mg/ft<sup>2</sup>

Company Supplied Data Sheet:

1	2/1/97	8am	37.2	2
2	2/1/97	10am	38.3	2
3	2/1/97	12pm	33.3	2
4	2/1/97	2pm	30.3	2
5	2/1/97	4pm	35.7	2
6	2/1/97	6pm	38.3	2
7	2/2/97	8am	32.1	2
8	2/2/97	10am	33.8	2
9	2/2/97	12pm	28.8	2
10	2/2/97	2pm	33.5	2
11	2/2/97	4pm	34.6	2
12	2/2/97	6pm	38.0	2
13	2/3/97	8am	33.8	2
14	2/3/97	10am	31.3	2
15	2/3/97	12pm	35.7	2
16	2/3/97	2pm	32.5	2
17	2/3/97	4pm	39.7	2
18	2/3/97	6pm	31.8	2
19	2/4/97	8am	36.5	2
20	2/4/97	10am	35.0	2
21	2/4/97	12pm	33.2	2
22	2/4/97	2pm	39.3	2
23	2/4/97	4pm	38.6	2
24	2/4/97	6pm	34.2	2
25	2/4/97	8pm	32.5	2

Field 1 is Sample Number  
Field 2 is the Date

Field 4 is the measurement  
Field 5 is the tank Number

Field 3 is the time collected

**QUESTIONS:**

**What should be done?**

1. Is there an SPC chart that was made expressively for this type of circumstance?
2. Why is it necessary to have a normal distribution?
3. If the process is not normal, would this change the type of chart we would use?
4. Can we ascertain whether the process is in control?
5. Can we perform a capability study?
6. What are our results?
7. What do they mean?
8. What, if anything should be done?

After generating a histogram from 100 readings, it was determined that the process **IS** normally distributed. This will allow us to monitor the process using an Individual 'X' and Moving Range Chart.

**Extracted Reading Data from Data Set**

1	2/1/97	8am	37.2	X	2
2	2/1/97	10am	38.3	1.1	2
3	2/1/97	12pm	33.3	5.0	2
4	2/1/97	2pm	30.3	3.0	2
5	2/1/97	4pm	35.7	5.4	2
6	2/1/97	6pm	38.3	2.6	2
7	2/2/97	8am	32.1	6.2	2
8	2/2/97	10am	33.8	1.7	2
9	2/2/97	12pm	28.8	5.0	2
10	2/2/97	2pm	33.5	4.7	2
11	2/2/97	4pm	34.6	1.1	2
12	2/2/97	6pm	38.0	3.4	2
13	2/3/97	8am	33.8	4.2	2
14	2/3/97	10am	31.3	2.5	2
15	2/3/97	12pm	35.7	4.4	2
16	2/3/97	2pm	32.5	3.2	2
17	2/3/97	4pm	39.7	7.2	2
18	2/3/97	6pm	31.8	7.9	2
19	2/4/97	8am	36.5	4.7	2
20	2/4/97	10am	35.0	1.5	2
21	2/4/97	12pm	33.2	1.8	2
22	2/4/97	2pm	39.3	6.1	2
23	2/4/97	4pm	38.6	0.7	2
24	2/4/97	6pm	34.2	4.4	2
25	2/4/98	8pm	32.5	1.7	2

Field 1 is Sample Number

Field 2 is the Date

Field 3 is the time collected

Field 4 is the measurement

Field 5 is the Moving Range

Field 6 is the Tank Number

## EXAMPLE #9

### Individual X and Moving Range Chart

**NOTE:** The formulas for the individual X and moving range chart are probably the easiest of all control charts.. The formulas for the Individual X chart are as follows:

$$CL = \bar{\bar{X}} = \frac{\sum X}{k} \quad \text{Where: } X = \text{individual readings}$$

$k = \text{number of samples}$

$A_2 = 2.66$  value from

constants table for;  $n = 1$

$$UCL = \bar{\bar{X}} + A_2 \bar{R}$$

$$LCL = \bar{\bar{X}} - A_2 \bar{R}$$

# EXAMPLE #9

## Individual X and Moving Range Chart

The formulas for the moving range chart are as follows:

$$CL = \bar{R} = \frac{\sum R}{k-1} \quad \text{Where: } R = \text{range}$$

$k-1$  = number of samples less 1

$D_4 = 3.268$  the value from the

constants table for;  $n = 2$

since 2 individual Xs were

used to find the range.

$$UCL = \bar{X} + D_4 \bar{R}$$

$$LCL = \bar{X} - D_3 \bar{R}$$

$D_3 = 0$  from table for any  $n < 6$

# EXAMPLE #9

## Individual X and Moving Range Chart

**NOTE:** The formulas for the individual X chart are as follows: s:

$$CL = \bar{\bar{X}} = \frac{\sum X}{k} = 868.0 / 25 = 34.72$$

$A_2 = 2.66$ , value from  
constants table for;  $n = 1$

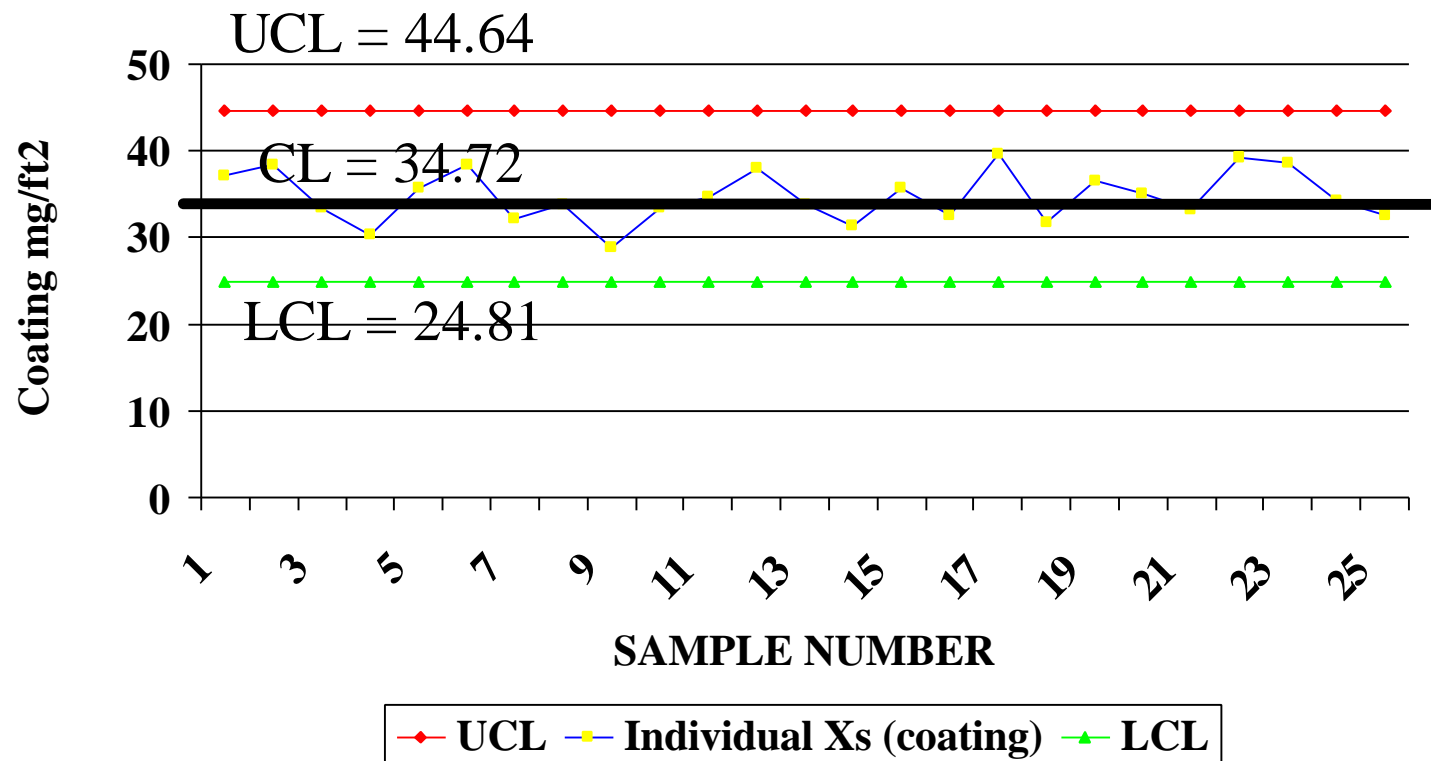
$\bar{R} = 3.73$ , calculation

$$UCL = \bar{\bar{X}} + A_2 \bar{R} = 34.72 + (2.66 * 3.73) = 44.64$$

$$LCL = \bar{\bar{X}} - A_2 \bar{R} = 34.72 - (2.66 * 3.73) = 24.81$$

# EXAMPLE #9

## Individual 'X' CHART



# EXAMPLE #9

## Individual X and Moving Range Chart

The formulas for the moving range chart are as follows:

$$CL = \bar{R} = \frac{\sum R}{k-1} = 89.5/24 = 3.73$$

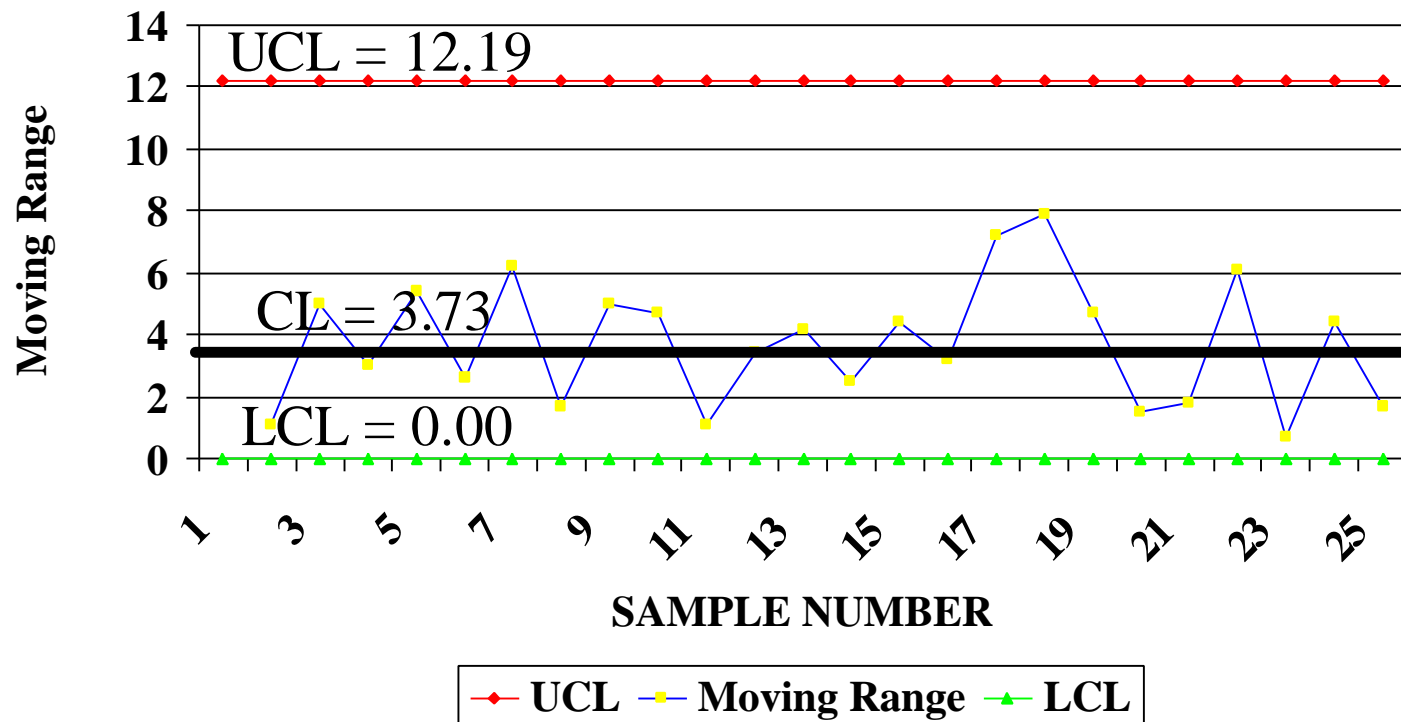
$D_4 = 3.268$  for  $n = 1$  and  $D_3 = 0$   
from the table for any  $n < 6$

$$UCL = D_4 \bar{R} = (3.268 * 3.73) = 12.19$$

$$LCL = D_3 \bar{R} = (0.00 * 3.73) = 0.00$$

# EXAMPLE #9

## Moving Range CHART



# EXAMPLE #9

## Process Capability & Performance

$$\hat{\sigma} = \frac{\bar{R}}{d_2} = \frac{3.73}{1.13} = 3.301 \quad \text{note: } d_2 = 1.13 \text{ for } n = 1 \text{ or } 2$$

$$C_p = \frac{\text{TOT TOL}}{6 \hat{\sigma}} = \frac{20}{6(3.30)} = 1.010$$

This says the process is marginally capable. But, now let us calculate the Cpk value.

Since the mean is closer to Cpl =

$$C_{pk} = \text{Min}(C_{pl}, C_{pu}) = C_{pl} = \frac{\bar{X} - \text{LSL}}{3 \hat{\sigma}} = \frac{9.72}{3(3.3)} = .982$$

Where: Cpl is Cp lower      Cpk is always the minimum of the  
          Cpu is Cp upper      two values, therefore Cpk = .982

## SUMMARY

Since we are only charting individual values and not averages, we do not have the **Central Limit Theorem** working for us. What does this mean? The Central Limit Theorem tells us that even if the data is not normal, taking subgroups, will automatically normalize the data. Normalized data is **Required** when using variables, ( $\bar{X}$  and R), SPC charts. But, since you are unable to obtain subgroups under these circumstances, the distribution of all single values collected for the Individual 'X' chart, **must be normal**. The control chart should have informed us that the Coating process is in control. The Capability analysis should have declared that the process was marginally capable,  $C_p = 1.01$ . However, the statistical analysis for performance calculated  $C_{pk} = .982$ . This is very close to marginally meeting specifications. When rounded the value actually equals one. Calculations of this type are not that accurate. Be very careful about rejecting a process as not meeting specifications with numbers like this. True as always, there is area for continuous improvement by eliminating some in-process variation.

### Example #10

This example is for a DCMC in-plant specialist, staff specialist and/or engineer

Ken's machine shop is manufacturing parts that must be cadmium plated prior to use. The item drawing specifies only dimensions after plating. Ken must decide on what dimensions he needs to list on the operational procedures for his machinist to work to, in-order to meet the after plating requirement on the drawing. Ken knows from past performance that the plating process utilized will yield a thickness that ranges from .002" to .005". From this information Ken has derived the following target values.

<u>Part</u>	<u>Drawing Requirements</u>	<u>Target Value</u>
A	3.750 $\pm$ .010	3.745 $\pm$ .007
B	5.125 $\pm$ .008	5.121 $\pm$ .006
C	2.126 $\pm$ .013	2.122 $\pm$ .011
D	2.760 $\pm$ .009	2.756 $\pm$ .007

Claudia is the Government engineer assigned to Ken's Facility and has been asked by the buying command to monitor this process. However, very few numbers of each of the 4 parts are made. Ken has zeroed out his gages to the target values so that the digit(s) obtained from his in-process inspections is in thousandths. Target Charts are control charts utilized to monitor a process which produces a particular characteristic on different parts. They track variation of a process from a set target value. For example, without the coating process the target value could well be the nominal value or mean tolerance dimension.

### QUESTIONS:

#### What should be done?

1. How is Claudia going to monitor this process?
2. Are there any criteria that will not allow you to place all the parts on the same control chart?
3. What does the Control chart tell you?
4. What must be done with the ranges?
5. Can Cp and Cpk values be obtained for the whole process or must they be calculated for each part?
6. How much stock can we take in the Cp and Cpk values.
7. What do the results tell you?

The following table shows the data obtained during the in-process inspection:

1	6/11/98	A	+5	+2	+1	+8	+2.7	4
2	6/15/98	A	-4	+3	0	-1	-0.3	7
3	6/16/98	A	0	-2	-1	-3	-1.0	2
4	6/17/98	B	-2	+4	+2	+4	+1.3	6
5	6/19/98	C	-5	+3	0	-2	-0.7	8
6	6/22/98	C	+1	-3	-5	-7	-2.3	6
7	6/23/98	D	0	-1	+1	0	0.0	2
8	6/26/98	B	-2	+5	+4	+7	+2.7	7
9	6/30/98	B	0	+4	+1	+5	+1.7	4
10	7/07/98	B	-2	-1	-3	-6	+2.0	2
11	7/09/98	D	-3	+2	-1	-2	-0.7	5
12	7/10/98	D	+4	-3	-1	0	0.0	7
13	7/11/98	D	+4	+2	+4	+10	+3.3	2
14	7/17/98	D	-2	+4	+1	+3	+1.0	6
15	7/18/98	C	-2	+1	-2	-3	-1.0	3
16	7/19/98	C	-1	-1	+1	-1	-0.3	2
17	7/21/98	C	0	+1	-2	-1	-0.3	3
18	7/22/98	C	+1	-1	+2	+2	+0.7	3
19	7/24/98	A	+3	0	-4	-1	-0.3	7
20	7/25/98	A	+1	-3	-2	-4	-1.3	4
Sum							+2.8	90

Field #1 Sample Number  
Field #2 Date  
Field #3 Part designation  
Field #4 Reading #1  
Field #5 Reading #2  
Field #6 Reading #3  
Field #7 Sum  
Field #8 Xbar or Average  
Field #9 Range

**NOTE:** The readings for all the parts are the +/- differences in thousandths from the target values.

# EXAMPLE #10

## Target Xbar & R Chart

**NOTE:** The formulas for the Target Xbar & R chart are the same as for the regular variables Xbar & R chart. The formulas for the Target X chart are as follows:

$$CL = \bar{\bar{X}} = \frac{\sum \bar{X}}{k} \quad \text{Where: } X = \text{individual readings}$$

k = number of samples

A<sub>2</sub> = 1.02 value from

constants table for; n = 3

$$UCL = \bar{\bar{X}} + A_2 \bar{R}$$

$$LCL = \bar{\bar{X}} - A_2 \bar{R}$$

# EXAMPLE #10

## Target Xbar & R Chart

**NOTE:** The calculations for the target Xbar chart are as follows:

$$CL = \bar{\bar{X}} = \frac{\sum \bar{X}}{n} = 2.80 / 20 = 0.14$$

$A_2 = 1.02$ , value from  
constants table for;  $n = 3$

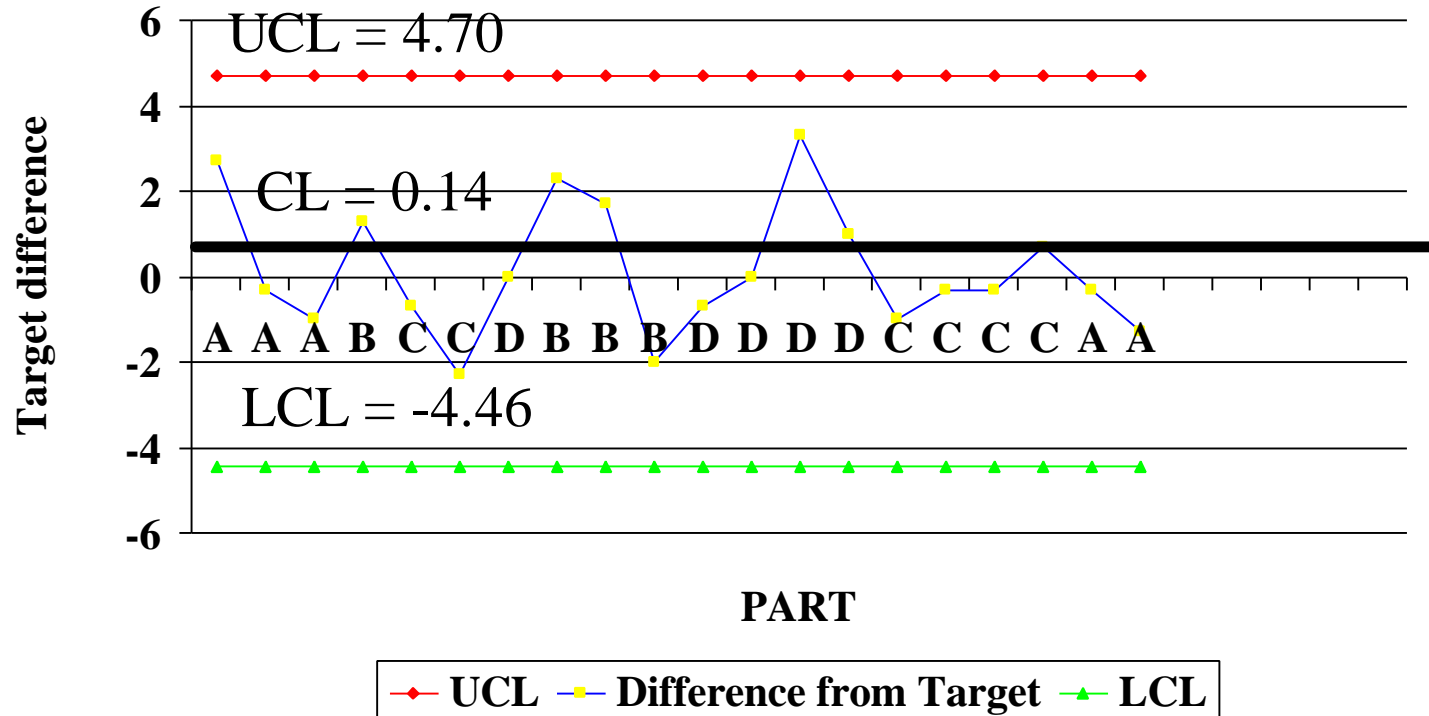
$\bar{R} = 4.50$ , calculation

$$UCL = \bar{\bar{X}} + A_2 \bar{R} = 0.14 + (1.02 * 4.50) = 4.70$$

$$LCL = \bar{\bar{X}} - A_2 \bar{R} = 0.14 - (1.02 * 4.50) = -4.46$$

# EXAMPLE #10

## TARGET $\bar{X}$ CHART



# EXAMPLE #10

## Target Xbar & R Chart

The formulas for the Target range chart are as follows:

$$CL = \bar{R} = \frac{\sum R}{k} \quad \text{Where: } R = \text{range}$$

k = number of samples

$D_4 = 2.57$  the value from the constants table for;  $n = 3$

$$UCL = D_4 \bar{R}$$

$$LCL = D_3 \bar{R}$$

Since 3 were used to find the

range,  $D_3 = 0$  from table for any

$n < 6$

# EXAMPLE #10

## Target Xbar & R Chart

The formulas for the Target range chart are as follows:

$$CL = \bar{R} = \frac{\sum R}{k} = \frac{90}{20} = 4.50$$

$D_4 = 2.57$  the value from the  
constants table for;  $n = 3$

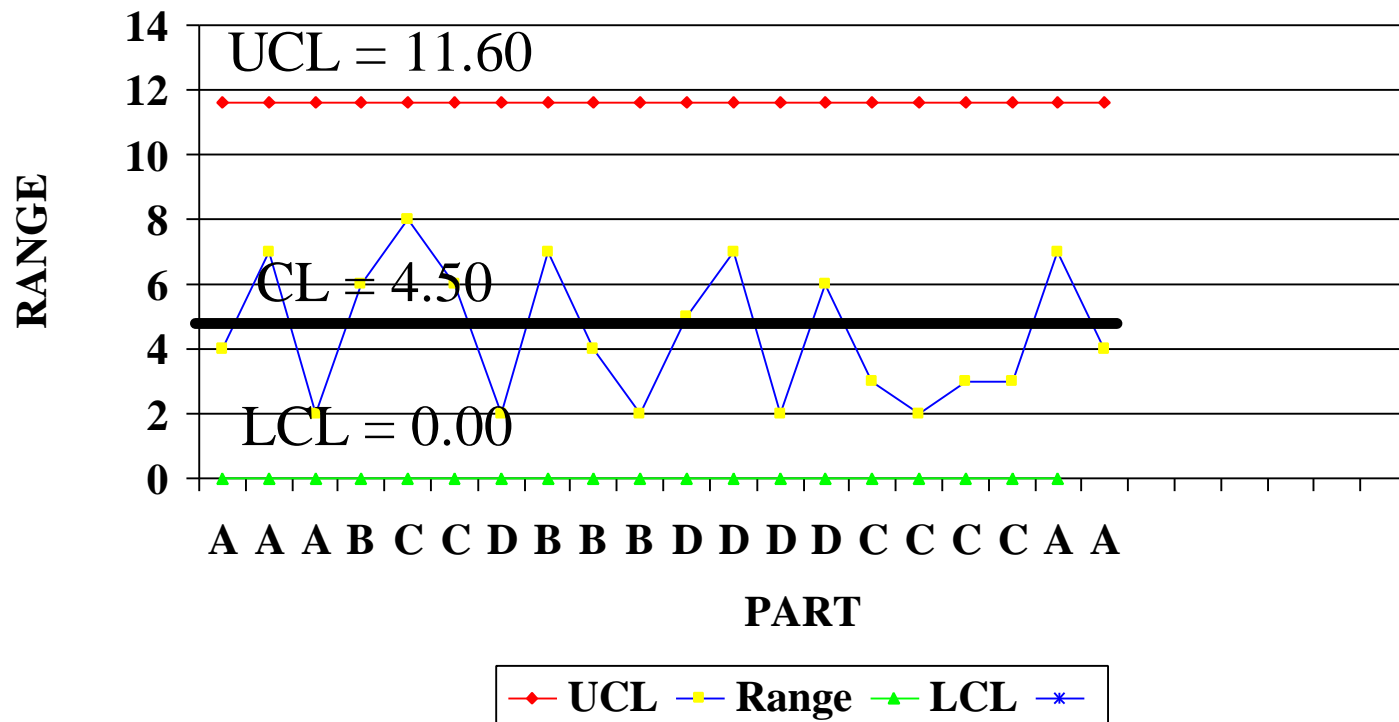
$$UCL = D_4 \bar{R} = (2.57)4.5 = 11.565 = 11.6$$

$$LCL = D_3 \bar{R} = (0.00)4.5 = 0.00 = 0$$

$D_3 = 0$  from table for any  $n < 6$

# EXAMPLE #10

## RANGE CHART



# EXAMPLE #10

## Target Xbar & R Chart

**NOTE:** The formula to see if any one part may be charted with all of the others on a Target chart is:

$$.77 < \frac{\bar{R}_{\text{suspect}}}{\bar{R}_{\text{total}}} < 1.3$$

$$\text{e.g. Part "D"} \quad \bar{R} = \frac{22}{5} = 4.4$$

$$\bar{R}_{\text{total}} = \frac{90 - 22}{20 - 5} = 4.533$$

Therefore:

$$\frac{4.40}{4.53} = .9713 \text{ which is greater than } .77 \text{ and less than } 1.3$$

Part "D" can be plotted with the rest.

# EXAMPLE #10

## Capability Parts A,B,C & D

$$\hat{\sigma}_A = \frac{\bar{R}}{d_2} = \frac{4.80}{1.69} = 2.840$$

$$Cp_A = \frac{TOT\ TOL}{6\ \sigma_A} = \frac{14}{6(2.840)} = 0.822$$

**This says that Part 'A' is not capable but close to the border line. Remember, Calculating Cpk, values are not necessary when the Cp value tells us that the process is not capable.**

$$\hat{\sigma}_B = \frac{\bar{R}}{d_2} = \frac{4.75}{1.69} = 2.810$$

$$Cp_B = \frac{TOT\ TOL}{6\ \sigma_B} = \frac{12}{6(2.810)} = 0.712$$

**Same analogy as in Part 'A', Part 'B' is also not capable.**

## SUMMARY

The Short Run "Target" chart is used to monitor processes in situations where the same process produces only a small number of many parts. The range variation formula will determine whether or not one individual part may be charted with the others; but remember, you must have at least ten points for the part before you can make this determination. You must also remember to back out from the range average all suspected part ranges. We must be extremely careful when calculating the  $C_p$  and  $C_{pk}$  values. First of all,  $C_p$  and  $C_{pk}$  values are not valid for the process; just individual parts. Also, a small number of readings pretty much invalidates  $C_p$  and  $C_{pk}$  values. As, you obtain more reading the  $C_p$  and  $C_{pk}$  value validity will get stronger. The control chart should have told you that the process seems to be in control. Using the current data, the Capability study should have told you that Parts A,B and D are not capable and part C is marginally capable. Note however, that since you have too few points at this time, nothing yet can be firmly stated about process capability and performance. In addition, since the capability of parts A,B and D were fairly close to one, capturing additional measurements may indeed show these parts as being capable.

## ***EPILOGUE***

This document provides guidance on the use of statistical tools. I was an attempt to reacquaint DCMC personnel with Statistical Process Control (SPC) charts and the importance of their use when monitoring a process. The importance of using SPC and other statistical tools cannot be overstated. Continuous quality improvement is a basic concept currently embedded in the Department of Defense (DOD)/Defense Industries Quality Excellence Program. The DOD has stated that Military and Federal Specifications which prescribe fixed levels of nonconformances, such as Acceptable Quality Levels (AQLs) and Lot Tolerance Percent Defectives (LTPDs), inhibit quality improvements and effective competition based on excellence, and should be eliminated. While Military and Federal Specifications may continue to utilize sampling techniques, DoD procurement activities have been instructed not to include prescribed AQLs and LPTDs or other requirements for fixed levels of nonconformances. The DoD promotes the use alternate methods of acceptance to sampling, and specifically endorses the implementation and use of an SPC program. Realizing, that most DCMC personnel took a course in SPC over 10 years ago, this guide of worked out SPC and other statistical problems is offered for your assistance. Please address any comments to Rich Zerilli at 703 767-3371 or DSN 427-3371 or E-MAIL [richard\\_zerilli@hq.dla.mil](mailto:richard_zerilli@hq.dla.mil).